THE TRANSACTIONS OF THE FUEL CONFERENCE

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THE BEARING OF HIGH AND LOW TEMPERATURE CARBONISATION AND SYNTHETIC FUEL PROCESSES ON CANADA'S FUEL PROBLEMS

DEPARTMENT OF MINES, OTTAWA

B. F. HAANEL

Paper No. G1

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INTRODUCTORY

The extraordinary demand for fuels of all kinds, more particularly liquid fuels, during the European War, and to an even greater extent since then, and the difficulties encountered at times in maintaining production and distribution, have been responsible, more than any other agency, for the general interest of the peoples of practically the entire world in matters concerning the true value of Nature's supply of fuels, and the bearing which they have on present-day civilisation.

It was not very long ago, comparatively speaking, when coal was considered to be serviceable only for generating heat—a substitute

for wood—in fact its real value to mankind as the basis on which enormous industries have been erected, and on which their existence depends, was not realised even by technologists until quite recent times. When crude oil was discovered, and its use for many purposes became general, coal, though indispensable and invaluable for many purposes, passed somewhat into the background; but to-day it is rapidly gaining great prominence for the reason that now it is pretty generally understood that when the crude oil resources are exhausted the solid fuels will prove to be the principal source of liquid fuels for many generations. The quantities of both coal and oil were not long ago considered to be so great that they were spoken of as being inexhaustible. Neither is inexhaustible; in fact, predictions have been made many times that the crude oil reserves, at the present rate of consumption, will be exhausted in the not distant future. The world's coal reserves, on the other hand, will probably, at the present rate of consumption and taking into consideration increased future consumption, serve mankind for many generations to come; but those who are far-sighted can see the day when this invaluable natural resource will be exhausted. This remarkable change in the mental attitude of industrialists and the layman has been wrought principally by the discovery of the many varied and profitable uses for both solid and liquid fuels, and the growing impression of the absolute dependence not only of industries, but the economic and social fabric of practically the entire world on a steady and increasing supply of these commodities.

The most spectacular development in recent years has, of course, been in the design of prime-movers for the use of crude oil and its products, and their manufacture in enormous numbers. As a result, liquid fuels are to-day indispensable, and a sudden cessation in their production, or even a decrease in their supply, will react most disastrously not only on the industries directly dependent on them but on many other industries formerly entirely independent. This phase of twentieth-century civilisation, coupled with the knowledge that the natural oil resources are very limited and might at almost any time in the not distant future be exhausted, has stimulated to a high degree investigators and scientists in general to seek other sources of oils which can be depended upon to supply the requirements of mankind indefinitely.

These sources, it is now believed, are to be found in the solid fuels freely distributed over all parts of the earth. These fuels, to all intents and purposes, may be regarded as inexhaustible. The technical processes for the treatment of solid fuels, which have

been devised, experimented with, and in many cases tried out on a commercial scale, have all been devised with the object in view of so treating them that a solid residue suitable for heating purposes and oils to augment the supply of natural oils can be produced. It would appear that the use of a fuel for heating alone has in recent years been accorded a secondary place, and that industrial requirements have been considered of first and almost exclusive importance. In a country like Canada this would be an erroneous idea to entertain, since the actual dependence of human existence on a steady and increasing supply for heating is of the utmost importance. If man is not kept warm industries will not matter. Therefore, when considering the fuel problems and the fuel situation existing in Canada, first consideration has been given to the supply of a domestic fuel, and, indeed, it may be said without exaggeration that it was the unfavourable domestic fuel situation rather than the industrial situation which prompted the creation of government bodies for conducting investigations concerning means and ways for ameliorating the unfavourable fuel situation which has occurred more than once during the past few years. In Great Britain the effort to eliminate the smoke nuisance was in a large measure responsible for the development of the low temperature carbonisation process. This, of course, had no bearing on the efforts made in certain parts of Canada to introduce the high temperature carbonisation process, since these parts already were in the habit of burning a smokeless fuel, *viz.*, American anthracite. Therefore, one might rightly ask why so much time and money have been expended on low temperature carbonisation processes for the heat treatment of solid fuels, when a method long established and developed to the point almost of perfection, is already employed on a large scale in all civilised countries for the production of metallurgical coke, gas, and other by-products, including tar oils. This method of heat treatment is exemplified by the modern by-product recovery coke oven, in which a solid fuel is carbonised at a high temperature. This is a very pertinent question which might be profitably asked by those residing in the Dominion of Canada; and the purpose, therefore, of this paper is to bring to the attention of those interested in the design and development of processes for heat treating solid fuels, or for converting them into liquid fuels, the conditions obtaining in Canada regarding the distribution and use of fuels, both solid and liquid; since the successful introduction of any system or method for treating solid fuels depends on a steady and profitable market for the products produced. Canadians in recent years have

made vigorous attempts to place their domestic fuel supply on a more secure footing than that which obtained in the past. Interest was naturally aroused, and the mental state of the average Canadian, induced by anxiety and the wide distribution of reports and other articles setting forth the fuel situation, encouraged promoters to exploit processes for converting solid fuels into more desirable forms, with the production at the same time of liquid fuels. Discussions arose regarding the most satisfactory and efficient process to meet local conditions, and technical articles were published setting forth the advantages and disadvantages of various processes; but the question is not and never was whether an economic process for producing a satisfactory smokeless fuel and oils from coal exists, or whether one process may be better than another; but whether even a highly perfected and ideal process can succeed under the economic conditions obtaining at the present time in Canada.

Conditions Necessary for the Introduction of Heat Treating Processes

The successful introduction of any process for the conversion of a solid fuel, either into a solid residue, gas and oils, or into oils alone, depends upon an available market for all the products produced, and a market which must be situated within economic transportation distances of processing plant, coal mine, and consumer. The products of this plant, moreover, must be disposed of at a profit, in spite of the fact that they will be compelled to compete with the natural fuels already on the market,—fuels which householders have learned to use and depend upon, and consequently, fuels hard to displace. Therefore, the processed fuel will have to sell at a lower cost, or be of such superior quality that it will sell at the same or an even greater price. So far as Canada is concerned, the carbonised residue produced in any heat treatment process can only be disposed of for domestic purposes, except in limited and unimportant cases, inasmuch as the power requirements of the two most highly industrialised provinces of Ontario and Quebec are taken care of almost wholly by hydro-electric energy, and the other portions of Canada contiguous to coal supplies will be satisfied for some time to come to burn coal for power purposes in its natural state, that is, without heat treatment, unless it can be definitely shown that power can be produced from a processed fuel at a lower cost, in virtue of the credits derived from the scale of the by-products. This, it is well known, is not the situation in European countries, densely populated and highly industrialised, where the collieries are in many

instances contiguous to the processing plants, and where these in turn are adjacent to chemical and other industries, which constitute the logical consumers of certain if not all of the products. Moreover, the industrial countries of Europe possessing large coal measures and industrial plants, are not faced with the difficult problem of the rail transportation of coal one thousand or more miles from the mines to the consumers. This does constitute one of Canada's chief fuel problems—a geographical problem, and, therefore, one which cannot be solved by mechanical, chemical, or metallurgical processes, which have as their objective the conversion of one solid fuel into another solid form. The adverse effect of the geographical location of the coal resources, however, may be greatly ameliorated by the development of processes which are capable of economically converting a solid fuel into other forms, *viz.*, liquid or gaseous, which may then be economically transported through pipe lines. This will be dealt with later. This naturally leads to the fuel situation obtaining in the Dominion of Canada and the discussion of means and ways which have been devised for its partial solution.

Canada's Fuel Situation

Canada's fuel situation, which is the basis for all of her fuel problems, may be briefly stated as remoteness of coal measures from centres of population and industries, and absence, at present, of natural oils in sufficient quantities. Canada has within her confines solid fuel resources of great extent and of practically all types—but these are situated in the eastern and western extremities. The most populous and highly industrialised portions, unfortunately, lie midway between these sources, some 2,000 miles from the western and about 1,000 miles from the eastern. Thus, the problem becomes one of transportation. On the other hand, parts of this portion of Canada are only distant by rail and water 400 or 500 miles from the coalfields of the United States. It is natural, therefore, that the central portion of Canada drew her supplies of solid fuels for all purposes from that country, and to-day draws the major portion of her supplies. Lacking crude oils in sufficient quantities, she is practically dependent on the United States or some other country for those fuels and her requirements for liquid fuels are steadily increasing from year to year. The problem for meeting the demands for this commodity will in the not distant future become a most important one, since Canada ranks only second per capita to the United States in the number of motor vehicles and

internal combustion motors in daily use. Canada's coal resources, arranged to show the different kinds of coals in the different provinces, are shown in Table I. The interesting features of this table are the proportions which the different classes of coals bear to the total estimated coal reserves. Class B_2 and B_3, *viz.*, bituminous coking coals, represent but 6·8 per cent., and class A_2 and B_1, semi-anthracite and semi-bituminous non-coking coals, represent but 0·4 per cent. The sub-bituminous and lignite non-coking coals, D_1 and D_2, on the other hand, represent 92·8 per cent. of the total —these lignites are in no sense analogous to the brown coals of Europe with which they have often been compared.

As previously stated, the middle provinces, *viz.*, Ontario and Quebec, possess no coal measures of economic value, but like other parts of Canada possess large fuel resources in the form of peat. Large peat bogs, suitable for fuel purposes, are scattered throughout these two provinces and are situated favourably with respect to centres of population, rail and water transportation. This constitutes the chief native source of fuel, other than wood, and the latter is rapidly becoming too scarce to be considered a fuel, except locally. This, in brief, is the fuel situation.

Solid and Liquid Fuel Requirements

As a result of the fuel situation just outlined, Canada at present is forced to import over one-half of her solid fuels, and approximately 98 per cent. of her liquid fuels. The consumption of coal in Canada for all purposes is roughly 35,000,000 short tons, and of crude and refined oil products about 800,000,000 imperial gallons. The coal consumed in Canada may be regarded as extremely small in quantity when her area, population, and industries are considered. As a matter of fact, hydro-electric energy for both industrial and municipal purposes has made it possible to displace an equal quantity of coal; but even allowing for the coal equivalent of the hydro-electric energy, the coal consumption would still be small. Tables II. to VII., inclusive, show the production, importation, refining, and requirements of crude oil and motor fuel in Canada.

Fuel Requirements

The total consumption of coal for all purposes, as stated above, is approximately 35,000,000 tons per annum; of this total, about 6,000,000 tons represent the coals, anthracite, low volatile, and other solid fuels, imported for domestic purposes. About 800,000 tons are imported annually for gas manufacture, and this quantity

TABLE I.

CANADA'S COAL RESOURCES

Table arranged to show the different kinds of coals in the different Provinces.

Kinds of coal.	Class A_2 and B_1 (Semi-anthracite and semi-bituminous non-coking coals).	Class B_2 and B_3 (Bituminous coking coals).	Class D_1 and D_2 (Sub-bituminous and lignite non-coking coals)	Total.	Proportion of total.
	Metric tons.	Metric tons.	Metric tons.	Metric tons.	Per cent.
Nova Scotia	—	2,188,151,000*	—	2,188,151,000	0·5
New Brunswick ...	—	(151,000,000)	—	(151,000,000)	—
Saskatchewan	—	—	2,412,000,000	2,412,000,000	0·6
Alberta	1,811,000,000	2,081,800,000	382,500,000,000	386,392,800,000	93·2
British Columbia ...	—	23,771,242,000	60,000,000	23,831,242,000	5·7
Total ...	1,811,000,000†	28,192,193,000	384,972,000,000	414,975,193,000	
Proportion of total ...	0·4%	6·8%	92·8%		100·0

* This estimate includes 50,415,000 metric tons of Class "C"—(Cannel coal).

† This figure includes a comparatively small amount of Class A_2—(semi-anthracite) coal.

NOTE.—The 151,000,000 metric tons of Class B_2 (Bituminous) coal indicated for New Brunswick is the figure used for the total "probable reserves" for this Province.

The data tabulated above are the calculations of the "actual reserves—based on actual thickness and extent" of all coal seams of 1 ft. or over to a depth of 4,000 ft., as published by Dr. D. B. Dowling in Memoir 59—Geological Survey—Department of Mines, Canada. Dr. Dowling's approximate estimate of the probable reserves, including all seams to a depth of 6,000 ft., is roughly 800 billion metric tons, that is, nearly double the total for the actual reserves shown above.

is practically all consumed in the two provinces of Ontario and Quebec. In addition to the above, about 28,000,000 imperial gallons of fuel oil are burned for domestic heating in these two provinces. The remainder of the above imports and production of coal, crude and refined oils, is used for railway, power, industrial, and transportation purposes.

Domestic Fuel Supply

The domestic fuel supply of the provinces of Ontario and Quebec, which several times during the past twenty-five years was rather uncertain owing to industrial disorders in the countries from which the supplies were drawn, led to the creation in 1922 of the Dominion

TABLE II.

PRODUCTION OF CRUDE PETROLEUM IN CANADA

Year.	Provinces.			Total	
	Ontario bbs.	New Brunswick bbs	Alberta bbs.	bbs.	Imp. gallons.
1919	—	—	—	—	—
1920	180,071	5,148	11,032	196,251	6,868,785
1921	172,859	7,479	7,203	187,541	6,563,935
1922	164,732	7,778	6,559	179,068	6,267,380
1923	159,400	8,826	1,943	170,169	5,955,915
1924	154,368	5,561	844	160,773	5,627,055
1925	143,134	5,376	183,491	332,001	11,620,035
1926	137,850	10,544	216,050	364,444	12,655,540
1927	140,105	18,244	321,154	479,503	16,782,605

TABLE III.

IMPORTATION OF CRUDE PETROLEUM INTO CANADA

Year.	Imperial gallons.				
	Crude petroleum.	Petroleum for refining.	Gas, oils, etc.	Fuel and other oils.	Total crude petroleum.
1919*	298,540,725	—	—	—	298,540,725
1920*	311,719,057	—	—	—	311,719,057
1921*	391,292,960	51,947,659	—	—	443,240,619
1922*	397,603,716	80,303,615	—	—	477,907,331
1923	392,185,557	15,922	475,842	108,539,898	501,217,219
1924	465,958,509	55,758	139,745	94,243,999	560,398,011
1925	436,258,650	49,149	4,181,914	103,796,960	544,286,673
1926	570,383,547	5,472,250	60,562	91,711,217	667,627,576
1927	684,269,831	45,500	398,046	119,420,474	804,133,851

* Fiscal years.

TABLE IV.

REFINING OF CRUDE OIL IN CANADA

Year.	Imperial gallons.		
	Canadian crude.	Imported crude.	Total crude refined.
1919	8,210,537	292,796,016	301,006,553
1920	6,711,070	288,865,457	295,576,527
1921	6,089,217	367,380,201	373,469,418
1922	5,849,442	388,289,613	394,139,055
1923	5,906,028	402,904,711	408,810,739
1924	5,172,903	361,974,302	367,147,205
1925	12,337,192	432,781,409	445,118,601
1926	12,203,286	572,263,043	584,466,329
1927	—	—	—

TABLE V.

REQUIREMENTS OF CRUDE PETROLEUM FOR CANADA

Year.	Imperial gallons × 1000.			
	Total production.	Total importations.	Total exportations.	Net requirements.
1919	—	298,541	—	—
1920	6,869	311,719	—	317,588
1921	6,564	443,241	—	449,805
1922	6,267	477,907	—	484,174
1923	5,956	501,217	—	507,173
1924	5,627	560,398	—	566,025
1925	11,620	544,287	—	555,907
1926	12,656	667,628	21,043	659,241
1927	16,783	804,134	18,793	802,124

TABLE VI.

SUMMARY OF MOTOR FUEL IN CANADA

Year.	Imperial gallons × 1000.		
	Gasoline Apparent consumption for all purposes.	Benzene. Total prod. of light oils from coal.	Gasoline Consumption plus benzene available.
1919	90,072	—	90,072
1920	96,781	1,140	97,921
1921	161,434	1,366	162,800
1922	187,310	733	188,043
1923	173,979	2,980	176,959
1924	233,155	1,773	234,928
1925	249,411	2,051	251,462
1926	303,994	—	—
1927	—	—	—

TABLE VII.

PRODUCTION, IMPORTATION AND CONSUMPTION OF GASOLINE IN CANADA

Year.	Imperial gallons × 1000.			
	Production (mostly from imported crude).	Imports.	Exports.	Apparent consumption.
1919	90,072	—	—	90,072
1920	88,640	8,516	375	96,781
1921	121,942	40,265	773	161,434
1922	147,201	42,112	2,003	187,310
1923	125,237	49,959	1,217	173,979
1924	160,857	73,777	1,479	233,155
1925	166,698	84,324	1,611	249,411
1926	223,798	84,064	3,868	303,994
1927	—	108,194	2,463	—

Fuel Board. Its primary purpose is to institute a thorough study of the underlying causes of recurring coal shortages, and the methods by which they may be counteracted. To that end, a comprehensive programme of investigations was planned, which included a series of exhaustive inquiries in different directions. One of the principal of these inquiries was the investigation relating to "Coke as a Household Fuel in Central Canada." This investigation was prompted by the desire to find a source of fuel more dependable than anthracite. The bituminous coalfields of the United States, to the south of the Ontario border, were highly developed and capable of producing a much larger quantity of coal than could be consumed in that country. Moreover, many of the mines in the bituminous coalfields are operated by non-Union labour, consequently, the production would not cease were a strike in the Unionised mines to take place. Coke, again, had for a long time been used to some extent as a domestic fuel in those centres of population where gasworks were operated, and gas house coke, but more especially metallurgical coke, was recognised to possess many of the physical characteristics of American anthracite. Naturally, therefore, the by-product recovery coke oven was favoured as the type of plant which could be employed to the best advantage for the manufacture of a domestic fuel from coking bituminous coals.

High and Low Temperature Carbonisation of Coals

The by-product recovery coke oven, in which a coking coal or mixture of a coking and poor coking coal is carbonised at a high temperature, has reached a high state of development on the

American continent. The primary purpose of carbonising coking coals was for a long time the production of a coke suitable for blast furnace and foundry use. This is still one of the principal purposes —but the development of a domestic coke market has led to the extension on a large scale of the employment of this type of plant for the manufacture of a domestic fuel in conjunction with town gas. The by-product recovery coke oven has met with general success, and, wherever a suitable market exists for the gas produced and the ammonia and tar oils recovered, it has proven a profitable undertaking.

Low temperature carbonisation, on the other hand, is, comparatively speaking, new. In no instance has its development approached that of the high temperature oven, and most of the promising processes are now passing through the development stage. For certain purposes, it must be admitted, low temperature coke, when made from the proper coal, is superior to high temperature or metallurgical coke—but it is doubtful if this superiority would influence many householders in Central Canada to pay a higher price for the fuel. A free burning fuel is a necessity in countries where dwellings and business houses are heated by an open fireplace, but in Canada the heating of buildings by individual central heating plants is general, and the central heating plant for heating groups of dwellings, or other buildings, is increasing in favour. In the latter case a low grade of coal can be used to advantage. The cost of the fuel to the consumer is in any case the deciding factor, assuming, of course, that one fuel is as good as another.

Conditions Necessary for the Establishment of High Temperature Carbonisation Plants

The successful employment of a high temperature carbonisation process, as exemplified in the modern by-product recovery coke oven, depends upon:—

1. A profitable market for the coke produced.
2. A profitable market for the gas produced.
3. A market for the tar oils and other by-products.

Assuming the existence of a coke market—the success commercially of this type of plant will depend on a profitable gas market, which generally, so far as Central Canada is concerned, is a local market. Almost every municipality which requires a domestic solid fuel also requires domestic gas, and the demands for the latter appear to be increasing in the larger towns and cities. Tables VIII., IX. and X. show the production of illuminating and coke

TABLE VIII.

PRODUCTION OF ILLUMINATING GAS IN CANADA

Year	Coal gas.	Carbur'd water gas.	Mixed coal and water gas.	Vaporised oil gas.	Acetylene gas.	Total production.
	Cubic feet × 1000.					
1919	5,881,048	4,151,486	39,860	64,512	1,540	10,138,446
1920	7,191,737	5,281,311	162,683	64,015	1,987	12,701,733
1921	7,398,541	4,805,914	119,422	65,050	1,977	12,390,904
1922	7,404,253	5,037,242	111,693	58,731	1,648	12,613,567
1923	8,138,611	5,276,101	106,575	70,608	1,534	13,595,429
1924	7,991,915	5,061,064	103,218	69,621	1,584	13,227,402
1925	8,315,179	5,023,569	98,531	68,745	1,463	13,507,487
1926	—	—	—	—	—	—

TABLE IX.

PRODUCTION OF COKE OVEN GAS IN CANADA

Year.	Sold.	Used under retorts.	Otherwise used.	Not accounted for.	Total production.
	Cubic feet × 1000.				
1919	—	8,842,659	2,561,521	607,315	12,011,495
1920	—	834,602	8,220,657	106,442	9,161,701
1921	816,689	—	6,151,372	1,666,087	8,634,148
1922	155,000	490,175	4,358,712	1,069,876	6,073,763
1923	102,090	2,280,466	8,796,553	3,619,748	14,798,857
1924	935,602	5,125,920	2,375,792	—	8,437,314
1925	1,124,237	5,008,236	5,991,969	—	12,124,442

TABLE X.

TOTAL PRODUCTION OF GAS IN CANADA

Year.	Illuminating gas.	Cove oven gas.	Refinery still gas.	Natural gas.	Total.
	Cubic feet × 1000.				
1919	10,138,446	12,011,495	—	19,937,769	42,087,710
1920	12,701,733	9,161,701	—	16,845,518	38,708,952
1921	12,390,904	8,634,148	—	14,077,601	35,102,653
1922	12,613,567	6,073,763	706,840	14,682,651	34,076,821
1923	13,595,429	14,798,857	605,249	15,960,583	44,960,118
1924	13,227,402	8,437,314	1,186,787	14,881,336	37,732,839
1925	13,507,487	12,124,442	1,019,755	16,902,897	43,554,581
1926	—	—	1,532,430	19,208,209	—
1927	—	—	—	20,529,873	—

oven gas and the total production of gas, including natural gas, from 1919 to 1925, and for the latter up to 1927. Tar oils can be considered to have a value as raw material for further refining. The quantity produced depends, of course, on the coal carbonised, but generally averages about 10 to 12 imperial gallons per ton of coal. Light oils, *i.e.*, benzol, when recovered, amount to about 2½ imperial gallons per ton of coal, and the ammonium sulphate about 26 lb. per ton, though this varies with the nitrogen content of the coal.

The by-product recovery coke oven has in several instances replaced the conventional gas retort, and with complete satisfaction. This change is due in a large measure to the demand for a better domestic coke. When a by-product oven is installed for the primary purpose of producing a domestic and industrial gas, the quantity of coke produced depends on the gas demand. A situation might, consequently, arise when the coke demand could not be met, and such a condition cannot be easily changed. The remedy exists in an extension of the gas market perhaps into the industrial field.

A large variety of coals are available for carbonising in the high temperature oven, many of which will produce an entirely satisfactory coke when carbonised alone; while others produce an excellent coke when blended. When blending, which has now become almost common practice, is resorted to the yield of coke suitable for domestic, metallurgical, and foundry purposes, is high, *viz.*, over 75 per cent. So far as a contributing factor to augment the oil supply, this type of carbonising oven cannot be said to occupy an important place. The tar oils are absorbed by chemical plants where they are worked up into many varied products. One of the principal uses to-day is for road dressing.

Conditions Necessary for the Establishment of Low Temperature Carbonisation Plants

The profitable establishment of processes based on the low temperature carbonisation of solid fuels depends on:—

1. A profitable market for the carbonised residue.
2. A profitable market for the primary tar oils.

The main objective in heat treating a solid fuel at low temperature is to recover the maximum quantity of primary tar oils. This depends not only on the heat treatment at low temperature but on the kind of coal carbonised—hence, a more careful selection of the coal for treatment is necessary. According to the work on low

temperature carbonisation conducted on both coking and non-coking coals; in the Fuel Testing Laboratories, Ottawa, that class of coals which yields the largest quantity of tar oils also produces the best coke, and *vice versa*. The non-coking sub-bituminous and lignite coals produce only half the oil yield of that obtained from the bituminous coking coals. A coal which will yield a carbonised residue suitable for a domestic fuel without subsequent treatment, such as briquetting, is exceedingly hard to find. Generally, it may be found that the coals which can be most readily procured and at the right price, will yield a carbonised residue which is not suitable for a domestic fuel without subsequent treatment, or that only a small portion of the carbonised residue is suitable as it leaves the retort for such purposes. A factor which must always be kept in mind is the sale price of the finished fuel to the consumer, and so far as Central Canada is concerned, this price must not exceed the market price for metallurgical coke properly sized for domestic use. If the density of the low temperature product is markedly superior to high temperature coke, and its other physical properties more desirable, this fuel may command a higher price, but even under these conditions the price will have to compare favourably with anthracite, which will for many years to come be on the market, a serious competitor. Since blending of coals for low temperature carbonisation would not be resorted to, the quantity of coke produced will not in general be greater than that obtained with the by-product recovery oven.

The tar oils will generally exceed in quantity high temperature tar oils by about 5 to 15 imperial gallons to the ton of coal carbonised. Table XI. shows a comparison of high and low temperature carbonisation results on six typical Canadian bituminous coals, *viz.*, coals from the provinces of Nova Scotia, New Brunswick, Alberta, and British Columbia. This table is self explanatory. It will be noticed that the gas yield in all the low temperature tests is very low, *viz.*, between 3,000 and 4,000 cubic ft. This quantity is scarcely sufficient to supply the heat for carbonising. A low temperature carbonising plant, therefore, cannot replace the ordinary gas plant or the by-product recovery oven for the manufacture of gas.

Value of Primary Tar Oils in Canada

Low temperature "primary" tar oils obtained from twelve representative Canadian bituminous coals, contained from 10 to 24 per cent. "tar acids," *i.e.*, the constituents soluble in dilute NaOH, and

COMPARISON OF HIGH AND LOW TEMPERATURE CARBONISATION RESULTS ON SIX TYPICAL CANADIAN BITUMINOUS COALS

Bituminous coal carbonised, Province represented.	No. 1 Nova Scotia (Sydney area).		No. 2 New Brunswick (Minto area).		No. 3 Alberta (Mt. Park area).		No. 4 Alberta (Crowsnest).		No. 5 British Columbia (Crowsnest).		No. 6 British Columbia (Island).	
Proximate Analyses—												
Moisture ... ... %	2·2		1·2		1·5	1·9	0·7		1·2	1·0	2·4	
Ash ... ... %	3·9		14·8		7·8	12·1	10·8		4·8	4·3	13·3	
Volatile matter ... ... %	32·9		31·3		30·5	29·8	25·2		26·6	22·7	37·4	
Fixed carbon ... ... %	61·0		52·7		60·2	56·2	63·3		67·4	72·0	46·9	
Sulphur ... ... %	2·0		6·2		0·5	0·7	0·7		0·4	0·5	0·6	
Calorific value (B.Th.U. per lb)	14,215		12,699		14,085	13,158	13,575		14,500	14,970	12,365	
Carbonisation conditions (High or low temperature)	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Coke—												
Per cent. of coal carbonised ...	70·7	71·4	71·1	74·0	71·9	75·0	77·2	81·4	75·4	82·4	67·8	70·4
Pounds per short ton	1,414	1,428	1,422	1,480	1,438	1,500	1,544	1,628	1,508	1,648	1,356	1,408
Analyses of coke—												
Ash ... ... %	5·5	5·4	20·8	19·8	10·8	16·7	14·0	13·7	6·4	5·0	19·6	19·9
Volatile matter ... %	1·5	7·6	1·5	6·9	1·5	6·2	1·5	7·1	1·5	7·4	1·5	10·3
Fixed carbon ... %	93·0	87·0	77·7	73·3	87·7	77·1	84·5	79·2	92·1	87·6	78·9	69·8
Sulphur ... ... %	—	—	5·0	5·0	0·5	0·6	0·5	0·6	0·5	0·5	—	0·5
Calorific value (B.Th.U. per lb.)	—	14,045	—	12,043	—	12,418	—	12,933	—	14,483	—	11,871
Tar oils (water free)—												
Imperial gallons per short ton .	7·7	23·9	8·5	22·1	8·8	18·5	7·1	12·1	7·2	11·0	9·2	22·4
Specific gravity at 60°F. ...	—	1·031	—	1·033	—	1·037	—	1·039	—	1·059	—	1·008
Tar acids (Sol. in Dil. NaOH) %	—	23·9	—	13·3	—	13·0	—	13·0	—	10·0	—	24·0
Neutral oils (washed) ... %	—	43·5	—	36·4	—	38·7	—	54·1	—	53·0	—	49·0
Sp. Gr. of neutral oils	—	0·934	—	0·909	—	0·913	—	0·962	—	0·954	—	0·908
Light oils from gas (av. sp. gr. 0·7)												
Imperial gallons per ton ...	2·5	—	3·2	2·1	3·3	1·6	2·4	1·7	2·8	2·0	2·7	2·5
Ammonium sulphate—lb. per ton	33·7	2·9	16·7	4·3	21·0	10·5	12·1	7·8	17·8	7·5	30·6	11·5
Gas—												
c.f./short ton (debenzolised) ...	10,951	3,527	9,979	3,468	10,727	4,251	9,787	3,543	10,846	3,192	10,275	4,012
Density (air = 1)	0·34	0·69	0·34	0·62	0·35	0·46	0·32	0·53	0·34	0·52	0·40	0·54
B.Th.U. per cubic ft.	535	642	500	655	550	570	531	671	558	709	547	724
Quality of coke as household fuel for use in furnaces designed for anthracite	Good	Fair	Fair	Poor	Good	Fair	Good	Fair	Very good	Fair	Fair	Fair

from 43 to 65 per cent. neutral oils, the specific gravity, distillation range, etc., of which are shown in Table XII. It will be observed from the tables that the tar acids are quite uniform for the different coals tested, and that there is a remarkable uniformity of the neutral oils remaining after the tar acids have been removed. In this respect their use as substitutes for crude petroleum and the manufacture of motor spirits and other petroleum products is quite possible.

The general opinion, however, of the staff of the Fuel Testing Laboratories agrees with that repeatedly expressed by different authorities on the subject, *viz.*, "that low temperature tar cannot at present be given a higher value than fuel oil." In this connection the statement of Dr. Franz Fischer, page 30, "Conversion of Coal into Oils"—Fischer and Lessing—that "primary tar must be regarded as raw material, and not as a finished product of manufacture," is interesting.

Promoters have laid stress on the enhanced value of the "phenols" for purposes such as the preservation of wood; but when estimating the net value of the refined products they usually fail to give consideration to the cost of extraction and refining to meet special specifications regarding density, boiling point range, etc. The fact that hardwood tar oil—a low temperature carbonisation product—for a long time the principal source of creosoting preparations, has been replaced by by-product coke oven tar, is significant, and indicates that the prospect of obtaining revenue from the phenols and creosotes derived from Canadian coals, lignites, and peat, by low temperature carbonisation, will prove disappointing, at least, until the demand for such creosoting oils cannot be readily supplied from present sources. The use, in the raw state, of low temperature oils derived from these fuels for ore flotation, is promising, but the market is at present limited, and is controlled by the price of the high temperature tar oil products.

When estimating the value of low temperature—"primary"—tar oils for the production of motor fuels, it is necessary to consider the other Canadian sources of liquid fuels, *viz.*, shale oil and bituminous sands. The oil shale deposits of the provinces of New Brunswick and Nova Scotia, and the vast deposits of bituminous sands in the province of Alberta, are potential sources of liquid fuels from which motor spirits and other products, now almost wholly obtained from crude petroleum, can be manufactured. The principal reasons why these sources of oil have not been utilised for such purposes are the high cost of crude oil and bitumen as

TABLE XII.

NEUTRAL OILS FROM "PRIMARY" TAR FROM TWELVE CANADIAN BITUMINOUS COALS

Lab. No.	Coal used.	Neutral Oil. % of primary tar.	Gals. per ton.	Sp. Gr. at 60°F.	Distillation range. Temperature of successive 10% volume fractions. 1st drop	10%	20%	30%	40%	50%	60%	70%	80%	90%	End point
					°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
C-1	Sydney (N.S.)—32·9% vol. matter	43·5	10·5	0·934	71	144	181	209	258	274	288	318	346	368	380
C-2	Minto (N.B.)—34·0% vol. matter	65·0	13·7	0·932	88	140	185	220	250	280	307	325	350	370	380
4028	Springhill (N.S.)—30·8% vol. matter ...	50·0	9·2	0·945	95	145	171	204	245	273	300	327	359	387	415
4029	Stellarton (N.S.)—27·3% vol. matter ...	54·3	9·6	0·890	90	125	150	178	212	250	278	310	350	395	410
4034	Cadomin (Alta.) — 19·3% vol. matter ...	52·3	8·9	0·931	90	145	170	215	245	268	291	317	348	370	405
4035	Mt. Park ,, 29·8% vol. matter	38·7	7·2	0·913	90	147	178	205	228	254	270	285	305	332	370
4036	Greenhill ,, 25·2% vol. matter ...	54·1	6·6	0·962	96	150	183	221	256	282	310	342	370	389	420
4038	International (Alta.)—23·8% vol. matter ...	56·4	6·5	0·940	73	132	163	197	227	257	280	313	350	380	410
4039	Michel (B.C.)—27·3% vol. matter	50·4	7·3	0·967	82	142	165	200	242	267	293	320	349	380	405
4040	Coal Creek (B.C.)—22·7% vol. matter ...	53·0	5·8	0·954	98	145	175	203	242	270	297	330	356	387	410
4041	Cassidy (B.C.)—37·4% vol. matter	49·0	11·0	0·908	75	145	178	211	244	270	293	319	347	374	392
4042	Comox (B.C.)—30·9% vol. matter	52·0	9·9	0 968	78	140	180	215	247	273	289	324	352	385	395
	Average	51·6	8·9	0·937	85	142	173	207	241	268	291	319	349	376	399

"TAR ACIDS" FROM "PRIMARY TAR"

Lab. No.	Coal used.	% of tar.	Gals. per ton.	Sp.Gr. at 60°F.	1st drop	10%	20%	30%	40%	50%	60%	70%	80%	90%	End point
C-1	Sydney (N.S.) coal	23·9	5·7	1·075	—	206	212	215	223	227	249	305	324	342	347
C-2	Minto (N.B.) ,, ...	24·3	5·1	1·086	—	208	215	220	226	233	272	293	332	343	345
4028	Springhill (N.S.) coal	22·7	4·2	1·080	—	210	214	219	228	235	270	315	358	385	390
4029	Stellarton ,, ,, ...	14·3	2·5	1·092	—	206	215	221	229	240	290	339	373	380	385
4034	Cadomin (Alta.) ,, ...	13·7	2·3	1·082	—	210	217	223	227	252	300	332	365	381	385
4035	Mt. Park ,, ,, ...	13·0	2·4	1·052	—	210	212	214	217	222	224	234	266	284	290
4036	Greenhill ,, ,, ...	13·0	1·6	1·093	—	—	—	—	—	—	—	—	—	—	—
4038	International (Alta.) coal	13·2	1·5	1·090	—	—	—	—	—	—	—	—	—	—	—
4039	Michel (B.C.) coal	17·1	2·5	1·078	—	196	208	213	220	235	255	307	345	363	365
4040	Coal Creek (B.C.) coal	10·0	1·1	1·077	—	—	—	—	—	—	—	—	—	—	—
4041	Cassidy (B.C.) ,, ...	24·0	5·4	1·074	—	206	214	222	235	248	275	308	338	370	380
4042	Comox ,, ,, ...	18·7	3·6	1·081	—	192	200	206	213	222	250	305	328	340	365
	Average	17·3	3·2	1·080	—	205	212	217	225	235	265	304	336	354	361

compared with crude petroleum, ground oil, and the greater refining losses. Recent modifications, however, in refining methods due to pressure cracking processes, appear to alter this adverse situation, and now these deposits may be seriously considered as sources to be drawn on to augment the supply of motor fuels, the demand for which is rapidly increasing.

Recent tests[1] conducted on Canadian shale oil and bitumen obtained from bituminous sands, according to the Dubbs and Cross pressure cracking processes, respectively, show gasoline yields of nearly 60 per cent. of the crude shale oil, and roughly 40 per cent. of the (dehydrated) bitumen tested. Assuming a "motor spirits" yield of at least 32 per cent. from low temperature coal tar by pressure cracking of the original tar, a comparison of yields of motor fuel per ton which may be expected from these three sources, is tabulated as follows:—

	Imperial gallons per short ton.	
	Crude oil by carbonisation retorting or extraction.	Motor fuel (gasoline) by pressure cracking.
Shale oil	30 to 35	18 to 21
Bituminous sands	25 to 27	10 to 11
Bituminous coking coals	20 to 25	6 to 8
Lignite and sub-bituminous non-coking coals	7 to 12	2 to 4

The yield of 32 per cent. motor spirits is the average of two results obtained in pressure cracking tests and reported by Egloff and Morrell.[2] These tests were carried out at a temperature of 875°F. and a pressure of 100 lb. per sq. in., on low temperature tars, without the preliminary removal of the tar acids. The motor spirits produced contained 25 and 35 per cent. respectively, of tar acids, and the authors could see no particular reason why tar acids blended with hydrocarbons should not make a good motor fuel. If, however, these phenols and other acid constituents of the original low temperature tar are considered to be too valuable to leave in for cracking and refining, for use as a motor fuel, the motor spirits yield on the neutral oil content can be arrived at in the following manner:

[1] Investigations of Fuels and Fuel Testing, 1926.
[2] Proceedings of International Conference on Bituminous Coal, November 15, 1926, at Pittsburgh, Pennsylvania, U.S.A., page 788.

Referring to Table XII., it will be observed that the average neutral oil content is as high as 50 per cent. of the primary tar. Egloff and Morell report for neutral oil a motor spirit yield of over 50 per cent.; consequently, for a coal yielding 25 gallons of low temperature tar, the motor spirit yield from the neutral oil content will not be much in excess of 6 gallons per ton of coal carbonised, which yield is 2 gallons less than that shown for the maximum yield from bituminous coal.

The pressure cracking gasoline yields cited above, do not include the light oils scrubbed from the gas, and since this amounts to as much as 2 gallons, the motor fuel yields shown roughly represent the maximum quantities of gasoline suitable for utilisation in internal combustion engines, which can be obtained from a ton of shale, bituminous sands, and the different classes of coals treated.

Research Work Conducted in Fuel Testing Laboratories in connection with High and Low Temperature Carbonisation

Throughout the low temperature carbonisation tests carried out on the different classes of Canadian coals, the results of which are shown in Tables XI., XII. and XIII., the temperature was kept at 600°C. The coals were carbonised in the temperature-controlled electrically-heated lead bath retort which has been described in the Mines Branch publications.[3]

The high temperature carbonisation results shown in Table XI. were obtained in a special electrically heated "tube" furnace equipped with special condensing and scrubbing train.[4] In this apparatus the coal is carbonised at 850°C. in a pyrex glass combustion tube, open at one end, which is progressively heated from the open to the closed end. In this manner the reaction taking place in a horizontal by-product oven is, to a certain degree, duplicated. Since the yields resulting with this apparatus have been found to correspond closely with those obtained in by-product ovens, the results may with the application of determined factors be translated directly into commercial yields.

Box Coking Tests

A large number of Canadian coals were carbonised by the box

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[3] Investigations of Fuels and Fuel Testing for 1925, page 66.

[4] "Fuel in Science and Practice," Dec., 1926, page 566.

TABLE XIII.

TYPICAL LOW TEMPERATURE CARBONISATION RESULTS FOR CANADIAN FUELS

Fuels carbonised.			Carbonised residue.					Gas, tar oils, etc., per short ton.				
								Gas.			Dry tar oils.	
Kind of Fuel.	Moisture content.	Coking properties.	Temperature of carbonisation.	Nature of residue.	lb. per ton.	Volatile matter %	B.Th.U. per lb.	Cu. ft.	B.Th.U. per cu. ft.	$(NH_4)_2SO_4$ lbs.	Imp. gals.	Sp. Gr. (60°F.)
Hardwood	25%	Non-coking	300°–350°C.	Charcoal	550	18	12,700	3,500	300	0	8	1·07
Peat bricks	25%	,,	,,	,,	750	28	11,850	3,700	(325)	15	14	0·97
Sask. lignite coal ...	33%	,,	600°C.	Char	880	9	12,700	3,300	400	12	6	0·99
Alta. ,, ,, ...	16%	,,	,,	,,	1,170	9	13,300	4,500	450	9	7	0·99
Sub-bituminous coal	7%	,,	,,	,,	1,400	9	13,000	3,300	500	8	10	0·99
Bituminous coal ...	12%	Coking	,,	Coke	1,480	9	13,500	3,500	650	6	24	1·05

coking method prior to 1910, and the results reported in "Investigations of the Coals of Canada," Vol. I. Last year this method was utilised for the purpose of carrying out coking tests on Western Canada coals. In these tests, which were made in the by-product recovery coke ovens of the Winnipeg Electric Company, the coals were just coked alone and then blended with 75 per cent. of the imported (Chilton, Pa.) coal, which was at that time the only coal used for the manufacture of a domestic coke and gas. A summary of the results of these tests follows:—

Coals used.	Grading as foundry coke.	Grading as domestic coke.
Michel (B.C.) coal alone	Excellent	Very good
,, 25% and Chilton 75%	Excellent	Very good
Coal Creek (B.C.) coal alone	Excellent	Very good
,, ,, 25% and Chilton 75%	Excellent	Very good
Corbin (B.C.) coal alone	Poor	Fair
,, 25% and Chilton 75%	Good	Good
McGillivray (Alta.) coal alone	Fair	Fair
,, 25% and Chilton 75% ...	Good	Good
International (Alta.) coal alone	Fair	Fair
,, 25% and Chilton 75% ...	Good	Good
Hillcrest (Alta.) coal alone	Fair	Fair
,, 25% and Chilton 75%	Good	Good
Mt. Park (Alta.) coal alone	Good	Good
,, 25% and Chilton 75%	Good	Good
Cadomin (Alta.) coal alone	Fair	Fair
,, 25% and Chilton 75%	Good	Good
Greenhill (Alta.) coal alone	Fair to good	Good
,, 25% and Chilton 75%	Good	Good

The foregoing grading is based mainly on appearance, and is subject to revision when correlated with other general and chemical properties.

Full Size By-Product Recovery Oven Coking Tests

A survey of the coals of the Maritime Provinces was conducted during 1924 for the purpose of ascertaining the suitability of the coals of these provinces for the manufacture of a "domestic" coke. The results of this investigation were reported in "Investigations of Fuels and Fuel Testing" for that year. The preliminary analysis survey served as a basis for the selection of coals for carbonising in a commercial by-product recovery oven plant. Four coals were selected, and these were coked in the plant of the Hamilton By-Product Coke Ovens Limited, situated at Hamilton, Ontario. These coals were coked alone and then were blended, first with one another and then with imported Pocohontas semi-bituminous and Elkhorn

bituminous coals. A summary of the results with respect to coking qualities follows:—

Coal mixture carbonised.	Grading as foundry coke.	Grading as domestic coke.
"Besco" washed coal alone*	Good	Very good
Sydney (unwashed) coal alone	Poor	Good
,, 50% and Elkhorn 50%	Fair only	,,
,, 80% and Pocohontas 20%	Very good	,,
Springhill (N.S.) coal alone	Fair to good	Good
,, 50% and Elkhorn 50%	Fair only	,,
,, 80% and Pocohontas 20%	,, ,,	,,
Stellarton (N.S.) coal alone	No coke	No coke
,, 50% and Sydney 50%	Fair	Good
,, 50% and Elkhorn 50%	,,	,,
,, 80% and Pocohontas 20%	,,	,,
Minto (N.B.) coal alone	Sulphur too high	Good, but ash high
,, 50% and Springhill 50%	,, ,,	,, ,,
,, 50% and Stellarton 50%	,, ,,	,, ,,
,, 50% and Elkhorn 50%	,, ,,	,, ,,
,, 80% and Pocohontas 20%	,, ,,	,, ,,

* "Besco" coke from washed coal and produced in ovens at Sydney, N.S. used here as standard for the comparative grading shown.

In Table XIV. the typical analysis and general characteristics of Canadian coals and peat are given.

Disposal of Tar Oils

The disposal of tar oils at a price which would justify the selection of a low temperature carbonisation process will prove to be a most difficult proposition so long as crude petroleum can be obtained in sufficient quantities and at a low price. The disposal of tar oils at fuel oil prices would reduce the margin of profit to such an extent that the success of such an undertaking would be extremely uncertain. The chances of selling the finished fuel at a price in excess of by-product oven coke are very small for the reasons stated above; consequently, unless the cost of plant for carrying out the low temperature carbonisation is much lower per ton of coal carbonised,—assuming the same operating cost per ton as with the by-product recovery ovens—and the upkeep charges are low, low temperature carbonisation cannot be profitable, except in special cases.

Carbonisation of Low Grade Lignites

The low grade lignites of the provinces of Manitoba and Saskatchewan are greatly improved in calorific value by carbonisation, either at high or low temperature, but the tar oils resulting are of small

TABLE XIV.

TYPICAL ANALYSES OF CANADIAN COALS AND PEAT

Coals and peat.	Range of proximate analyses.				Calorific value, etc.	Sulphur %	Cooking properties.
	Moisture %	Ash %	Volatile matter %	Fixed carbon %	B.Th.U. per lb. as rec'd (wet) basis.		
Nova Scotia—							
Bituminous coals	1— 9	4—22	22—40	45—64	11,200—13,900	0·5—7·0	Fair to good.
New Brunswick—							
Bituminous coals	1—15	13—20	30—33	47—54	10,900—12,700	5·0—9·0	Fair to good.
Saskatchewan—							
Lignite coals	30—37	5—12	24—34	28—34	6,400— 7,500	0·3—0·9	Non-coking.
Alberta—							
Lignite coals	9—28	4—14	24—35	35—52	7,900—10,900	0·2—1·3	Non-coking.
Sub-bituminous coals	5— 9	5—17	27—37	46—53	10,000—12,000	0·1—0·3	Non-coking.
Bituminous coals	1— 5	5—20	20—31	50—69	11,300—14,300	0·1—1·7	Fair to good.
Semi-bituminous coals ...	0·5— 4	3—20	12—23	62—80	11,500—14,900	0·4—1·8	Poor to good.
Semi-anthracite coals	0·5— 2	6—18	8—13	70—82	12,200—14,300	0·5—0·7	Non-coking.
British Columbia—							
Sub-bituminous coals	3— 8	4—14	36—38	44—55	11,100—11,800	0·7—0·9	Non-coking.
Bituminous coals	0·5— 4	7—19	21—42	42—66	11,600—13,700	0·3—2·5	Fair to good.
Semi-bituminous coals ...	0·6— 2·5	2—16	17—24	71—77	13,800—15,100	0·5—0·9	Poor to good.
Ontario—Peat air-dried bricks ...	(25)	5	49	21	7,100	0·2	(Charcoal)

amount, and, in addition, are of uncertain value. When the market for domestic and industrial fuels, with certain specific characteristics, has been developed, these lignites might prove a profitable source of fuel for carbonising. In any event, however, the carbonised residue will have to be briquetted to meet the demands for both domestic and industrial purposes, except where a pulverised fuel of this kind is required for steam raising or other purposes, and, consequently, the financial success of such an undertaking will depend entirely on the cost and sale price of the fuel produced. The type of carbonising plant must, moreover, be of simple design, easy to operate, and have a large throughput; and the capital cost per ton of coal carbonised must be very low.

Liquefaction of Solid Fuels and the Manufacture of Synthetic Fuels

The increased quantity of tar oils which can be recovered when a solid fuel is carbonised at low temperature is the prime reason for the development of low temperature carbonisation processes. If all the fuel used for domestic purposes in the middle provinces of Canada, *viz.*, 6,000,000 tons, were carbonised at low temperature, the total quantity of primary tar oils which could be recovered would not be over 150,000,000 imperial gallons; and if this were all treated by temperature pressure cracking processes for the production of motor spirits the total quantity of motor spirits produced would not exceed 45,000,000 imperial gallons, which would be the chief product to be obtained, and this quantity of tar oils and motor spirits would be obtained from the carbonisation of imported coals, and, therefore, would have no effect upon one phase of Canada's fuel problem, *viz.*, independence of foreign sources for domestic and other fuel supplies. Moreover, since the quantity of tar oils recovered depends directly upon the quantity of coal carbonised, the quantity of tar oils cannot be appreciably increased above the amount stated, inasmuch as the market for carbonised residue in the form of a first-class domestic fuel would not exceed 6,000,000 tons. In order, therefore, to render this country less dependent than at present on foreign sources for its supply of solid and liquid fuels, some other method than low temperature carbonisation for treating solid fuels must be found. Those processes for the liquefaction of coal, according to Bergius, or the I.G. Farben Company, or the synthetic fuel process developed by Franz Fischer, appear to be the most promising.

Since the principal obstacle to the introduction of western coals

into the provinces of Ontario and Quebec is the high freight rate involved, a method which would permit the transportation of the heating value of these coals in the form of oils or gas would, in a large measure, overcome the problem of transportation. Crude petroleum is transported many hundreds of miles through pipe lines at a cost which per 100,000 heat units is materially below the cost when the same number of heat units are transported in the form of a solid fuel by rail. The technique of the various liquefaction processes, but more especially that developed by the I.G. Farben Company, has been brought to a high degree; but the cost of the oil produced, which cannot have a greater value than crude petroleum, is generally speaking, according to the writer's information, much in excess of the cost of the latter. During the last few years the price of fuel oil has dropped to such an extent that 28,000,000 imperial gallons are used annually for domestic heating purposes alone throughout the provinces of Ontario and Quebec, in competition with solid fuels formerly used for that purpose; and until the oil situation is stabilised, which will not take place until more is known definitely about the world's oil reserve, artificial processes for producing liquid fuels from solid fuels cannot succeed commercially. It is believed by many that this is but a temporary situation, and that in a very short time the predictions made so often by experts concerning the life of the oil resources of the world, will be justified; but just so long as crude oil can be obtained in sufficient quantities at the present low price per barrel there is but little probability of plants established for producing oils from coals, lignites, peat, oil shales and bituminous sands succeeding. However, since this situation may change within a very short time, it is absolutely necessary that every effort should be made, not only to accumulate data regarding the most promising of the processes for the conversion of a solid fuel into other forms, but vigorously to prosecute research work, so that when a shortage does take place and the exhaustion of the reserves of natural crude oils is imminent, Canada shall be in a position immediately to introduce an economic process for the production of oils, without seriously disorganising industries, transportation, etc., which would be the case were no processes available.

RÉSUMÉ

Une comparaison des procédés de carbonisation à haute et à basse température fait constater, de l'avis du présent auteur, qu'en tant que cela concerne le Canada en ce moment, le procédé à haute température, à savoir: le four

à coke à récupération des sous-produits, servira à fournir pour un certain temps à venir un combustible de ménage, vu que le combustible produit possède plusieurs des propriétés du charbon anthracite et qu'il peut être brûlé d'une façon satisfaisante dans les genres d'appareils de chauffage utilisés dans la majeure partie des maisons ordinaires. Bien plus, la demande de gaz pour des fins de ménage et autres, pousse arbitrairement au choix d'un procédé de carbonisation qui puisse produire suffisamment de gaz pour satisfaire aux exigences.

On fait remarquer que la carbonisation de la houille, dans tous les cas, serait limitée à la quantité de charbon utilisée en ce moment pour des fins de ménage dans les provinces d'Ontario et de Québec, vu que la quantité de combustible carbonisé qui peut être utilisée pour des fins industrielles est restreinte, et que les provinces de l'est et de l'ouest sont bien approvisionnées de combustibles solides et de gaz naturel, entièrement appropriés, dans leur état brut, à la production de force motrice et au chauffage. Actuellement et peut-être pour un certain temps à venir, les perspectives de succès qu'a l'introduction du procédé de carbonisation à basse température en vue de la fabrication d'un combustible de ménage seulement ne sont pas très brillantes.

L'abondante provision de pétrole brut et son coût peu élevé par baril ont créé une situation qui rend extrêmement difficile son remplacement par les huiles produites soit synthétiquement au moyen de la liquéfaction des combustibles solides ou de la carbonisation à basse température, soit par une combinaison de carbonisation à basse température et d'un procédé de combustible synthétique.

DIE WÄRMEÜBERTRAGUNG IN DEN WÄNDEN VON KOKSÖFEN

(HEAT TRANSFER THROUGH THE WALLS OF COKE OVENS)

KOKEREI-AUSSCHUSS DES BERGBAU-VEREINS ESSEN UND DES VEREINS DEUTSCHER EISENHÜTTENLEUTE

K. RUMMEL

Paper No. G2

CONTENTS

THE IMPORTANCE OF THE HEATING SURFACE—HEAT FLOW THROUGH THE OVEN WALL—EFFECTIVE HEAT—CONCLUSIONS RELATIVE TO GUARANTEES WHICH CAN BE GIVEN BY THE COKE OVEN CONSTRUCTOR AND RELATIVE TO COKE OVEN PRACTICE—SUMMARY ENGLISH TRANSLATION

(A) DIE HEIZFLÄCHE ALS WICHTIGE GRÖSSE. Die Wand zwischen den Heizzügen und der Kokskammer ist die "Heizfläche" des Koksofens. Ihre Grösse je Ofen lässt sich ausdrücken als

Heizfläche $F = 2 \times$ Kokskammerbreite $B \times$ beheizte Höhe H

H kann bei senkrechten Heizzügen genommen werden als Entfernung von Unterkante Heizzugsohle bis Oberkante Horizontalkanal.

Ebenso wie beim Kessel lässt sich die Leistung L angeben als Erzeugung je m² Heizfläche und Stunde. Demnach können wir die Leistung des Koksofens messen als erzeugte Tonnen Koks je m² Heizfläche und Stunde. Genauer noch und für manche Zwecke besser geeignet, ist die Angabe der Leistung in kcal/m² Heizfläche und Stunde. Während des Verlaufes einer Garungsperiode wird diese letztere Leistung sich ständig ändern.

Bezeichnen wir diese Leistung als "nutzbare" Wärmemenge ("Nutzwärme") und nennen wir sie Q_n, so drückt Q_n ohne weiteres die Ofenleistung aus. Wird weiterhin dem Koksofen je m² Heizfläche die Wärmemenge Q_b =(Heizwert des Heizgases $\times$ Gasmenge je m²) zugeführt, so ist der Wirkungsgrad des Ofens $\eta = \frac{Q_n}{Q_b}$

Die Wärmebilanz des Ofens lässt sich folgendermassen schreiben:

BILANZ I (Veredelungsbilanz).

Herkunft der Wärme.		*Verwendung der Wärme.*	
I aus dem Heizgas ...	kcal	I Nutzwärme ($Q_n . F$) ...	kcal
II aus der fühlbaren Wärme der angesaugten Verbrennungsluft ...	,,	II Abgasverlust ...	,,
III aus der fühlbaren Wärme der eingesetzten Kohle (nicht als deren Heizwert!) ...	,,	III Strahlung und Leitung ...	,,
Summe ...	kcal =	Summe	kcal

Wollte man ganz genau rechnen, so müsste man zu dem Posten I auf der rechten Seite noch insofern eine kleine Korrektur machen, als nicht der gesamte Wärmefluss durch die Wand eines Kessels oder Koksofens mit dem in dieser Bilanz als Nutzwärme bezeichneten Betrag identisch ist; ein Teil des Strahlungs- und Leitungsverlustes des Koksofens stammt nämlich aus der Wärme der Kokskammer, und der Kokskammer wird die Wärme durch die Wand zugeführt. Insofern deckt sich also der Wärmefluss durch die Wand nicht ganz mit der Nutzwärme, indessen ist der Fehler nicht gross. Nehmen wir an, dass die gesamten Strahlungs- und Leitungsverluste in der Bilanz etwa 6 % ausmachen, und rechnen wir weiter überschläglich, dass ⅓ dieses Verlustes durch den Unterofen bedingt ist, ein weiteres Drittel anteilig auf die Heizzüge und das letzte Drittel auf die Kokskammer entfällt, so würde der Gesamtfehler 2 % betragen. Will man diese 2% berücksichtigen, so müsste man sich nach der Gleichung richten:

Nutzwärme = (durch die Wand gegangene Wärme)—(⅓ Strahlungs- und Leitungsverlust).

Die rechnerische Berücksichtigung dieser Gleichung macht keinerlei Schwierigkeiten, da, wie unten gezeigt werden wird, der Strahlungs- und Leitungsverlust mit genügender Genauigkeit gemessen werden kann; es ist nicht notwendig, ihn, wie es bisher üblich war, als Restglied der Bilanz zu bestimmen.[1]

Es ist gleichgültig, ob sämtliche Posten der obigen Bilanz auf 1 m² Heizfläche und Stunde oder auf eine Garungsperiode oder auf 1 m²

[1] Hierüber siehe ausführlicher Teil E.

Heizgas oder auf 100 kcal Heizgas bezogen werden. Im letzteren Falle sind alle Werte der Bilanz in Prozent der zugeführten Heizgasmenge ausgedrückt.

Die aufgestellte Bilanz unterscheidet sich von der üblichen Form der Wärmebilanzen von Koksöfen, wie sie in nachstehender Bilanz II dargestellt ist, besonders dadurch, dass auf der linken Seite der Bilanz der Heizwert der in den Koksofen eingesetzten Kohle *nicht* erscheint.

BILANZ II (Verbundene Stoff- und Wärmebilanz).

I	Heizwert der eingesetzten Kohle ...	kcal		I	Heizwert des Kokses ...	kcal
II	aus dem Heizgas ...	,,		II	Heizwert des ausgebrachten Koksgases ...	,,
III	Fühlbare Wärme von Kohle und Verbrennungsluft ...	,,		III	Fühlbare Wärme von Koks und Gas ...	,,
				IV	Latente und fühlbare Wärme des Wasserdampfes ...	,,
				V	Abgasverlust ...	,,
				VI	Strahlung und Leitung ...	,,
	Summe	kcal	=		Summe ...	kcal

Diese Kohle ist in der Bilanz I also nicht als *Brenn*stoff, sondern als *Werk*stoff betrachtet.

Es ist in der Bilanz I also ebenso vorgegangen, wie dies beispielsweise beim Martinofen üblich ist. Das in diesen eingesetzte Eisen wird als Werkstoff behandelt, der einem Veredlungsprozess unterliegt. Die Bilanz I ist also eine Veredlungsbilanz. Auch im Martinofen verbrennt ein Teil des eingesetzten Eisens; die durch diese Verbrennung entwickelte Wärme ist für die Wärmebilanz durchaus nicht unwichtig und muss in ihr erscheinen; trotzdem wird niemand auf den Gedanken kommen, das gesamte eingesetzte Eisen mit dem Wärmewert in die Bilanz einzuführen, den dieses gesamte Eisen haben würde, wenn es im Martinofen verbrennen würde. Genau den gleichen Gedankengang wenden wir auf den Koksofen an.

Bevor wir die Bilanz weiter zergliedern sei zunächst die Art des Wärmeflusses durch die Wand betrachtet.

(B) Der Wärmefluss durch die Wand.[2]—Beim Einfüllen der

[2] Die nachstehend beschriebenen Messungen sind von Dipl.-Ing. Steinschläger auf einer Zeche des rheinisch-westfälischen Kohlenreviers im Auftrage der Wärmestelle des Vereins deutscher Eisenhüttenleute vorgenommen worden.

Kohle in die Kokskammer ist die Kohle kalt, die Kammer heiss. Die Temperatur der von der Kohle berührten Wand sinkt in ihren äussersten Schichten an der Berührungsstelle der Kohle auf eine Temperatur, die nur wenig höher liegen mag als 100°C (Siedepunkt des mit der Kohle eingeführten Wassers), um dann sofort wieder zu steigen. Das Steigen geht erst schnell, dann langsamer vor sich, dauert aber bis zum Ende der Garungszeit an. Bei der Abkühlung der Wand wird ihr ein Teil ihres Wärmeinhalts entzogen. Im weiteren Verlauf der Garungsperiode wird später neue Wärme in die Wand gespeichert. Die von der Wand an den Koks abgegebene Wärme muss nach diesen Überlegungen im Sinne der schematischen Darstellung der Abb. 1 Kurve 1 verlaufen. Bei der Speicherung sinkt auch die Temperatur der Wand des Heizzuges. Es wird daher im Anfang der Garungszeit mehr Wärme von dem Heizzug auf die Wand übertragen, als am Ende der Garungszeit. Daher muss die von dem Heizzug auf die Wand übertragene Wärme schematisch nach Kurve 2 Abb. 1 verlaufen. Fläche A bedeutet dabei Entspeicherung aus der Wand, Fläche B Speicherung in die Wand.

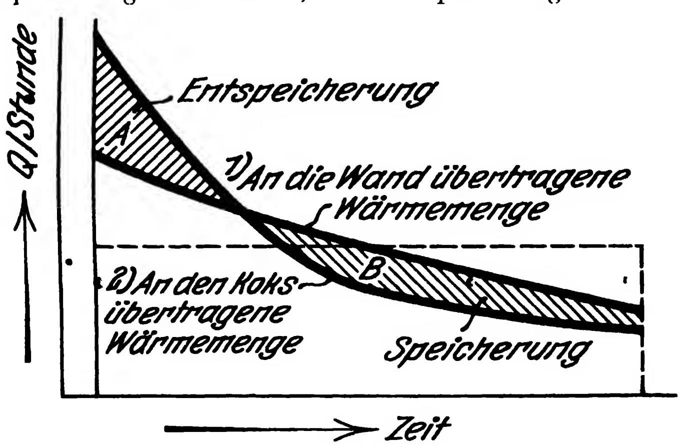

Abb. 1.—Theoretischer Wärmefluss in der Wand eines Koksofens in Abhängigkeit von der Garungszeit.

Gegenüber dem in Abb. 1 schematisch dargestellten theoretischen Verlauf ergaben Messungen, beispielsweise an einer Silika-Batterie, den in Abb. 2 dargestellten Verlauf.[3]

Die Kurve der Abb. 2 ist auf folgende Weise entstanden. In die Wände von Koksöfen wurden Thermoelemente gemäss Abb. 3 eingebaut und während mehrerer Garungsdauern

[3] Bei der Darstellung der Kurven wurden jeweils die Mittelwerte zwischen 2 errechneten Punkten durch eine gefühlsmässig eingetragene Linie verbunden.

abgelesen. Aus dem so aufgenommenen Temperaturfluss liess sich der Wärmefluss in die Wand entwickeln, indem man eine bestimmte Wärmeleitzahl λ für das Mauerwerk der Wand annahm. Da ferner aus der Temperaturänderung der Wand die gespeicherte oder entspeicherte Wärmemenge errechnet werden kann, so ist es nunmehr auch möglich, die Wärmemenge zu berechnen, die an den Koks abgegeben worden ist.

Die Abweichungen von dem Schema der Abb. 1 sind beträchtlich. Es finden mehrfach Entspeicherungen und Speicherungen statt, die, wie die Untersuchung im einzelnen gezeigt hat, auf Ungleichmässigkeiten in der Beheizung zurückzuführen sind. Die Unregelmässigkeiten schwanken ziemlich willkürlich bei verschiedenen Versuchen und sind zum Teil noch erheblich stärker, als aus Abb. 2 erkenntlich ist.

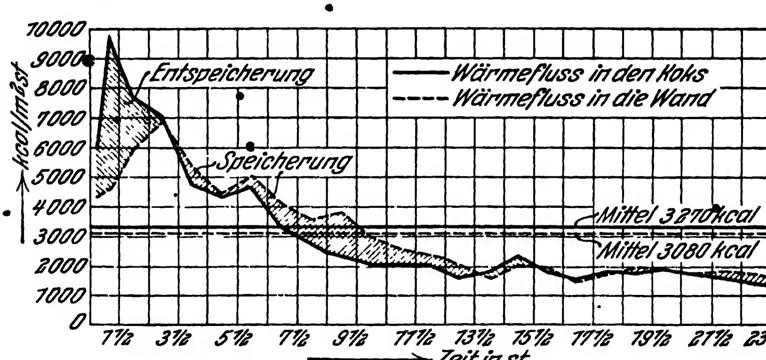

Abb. 2.—Gemessener Wärmefluss in der Wand einer Silikabatterie in Abhängigkeit von der Garungszeit.

Abb. 2 stellt insbesondere auch insofern keinen Normalfall dar, als während der betreffenden Garungsperiode die Beheizung gegen Ende der Garungsperiode ein wenig schwächer wurde und infolgedessen gerade gegen Ende der Garungsperiode die mehrfachen Speicherungen und Entspeicherungen auftreten, während bei gleichmässig durchgeführter Beheizung gegen Ende der Periode dauernd Speicherung stattfinden musste, allerdings mit abnehmender Tendenz, da das Mauerwerk bei ins Unendliche fortgesetzter Beheizung nur bis zu einem endlichen Werte Speicherungswärme aufnehmen kann.

Die mehrfachen Speicherungen und Entspeicherungen, die in Abb. 2 auftreten, haben nichts mit den einzelnen Umstellperioden zu tun. Zwar äussern sich auch die einzelnen Umstellperioden in

wechselnder Speicherung und Entspeicherung. Bei der Berechnung des Schaubildes 2 sind aber diese Speicherungen durch Mittelwertbildung aus den gemessenen Linien ausgeschaltet worden. Im übrigen dringen die Schwankungen der halbstündigen Umstellperioden nicht bis zu dem Koks vor, sie klingen innerhalb der Wand ab.

In Abb. 4 stellt die obere Linie die höchste, die untere Linie die niedrigste Temperatur während einer Umstellperiode an einem aus den Messungen durchgerechneten Beispiel dar. Die Grösse der Speicherung infolge des Umstellens betrug während einer halben Stunde bei der Messung an einer Silika-Batterie ca 600 kcal/m², bei einer Schamotte-Batterie ca 450 kcal/m².

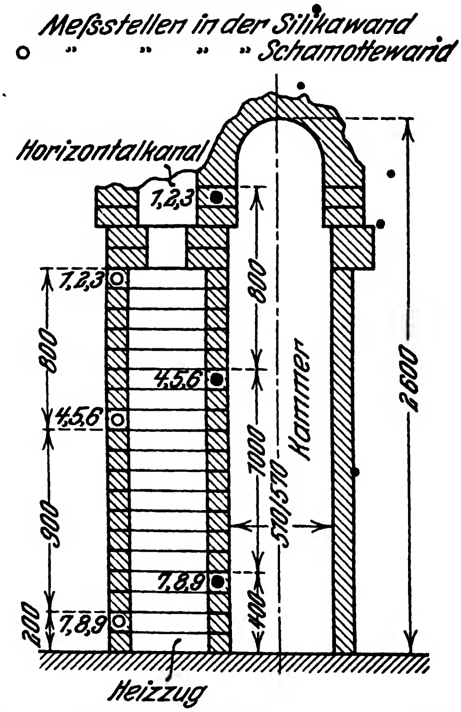

Abb. 3.—Lage der Thermoelemente in der Heizwand.

Abb. 2 gibt auch noch die Mittel der Kurven 1 und 2 wieder. Man erkennt hieraus, dass während der betreffenden Garungsperiode insgesamt eine Entspeicherung von rund 4 500 kcal = 6 % der der Kokskammer zugeführten Wärme stattgefunden hat. Es ist bemerkenswert, dass dergleichen Möglichkeiten mit so erheblichen Werten vorliegen. Dies zeigt, dass man bei Versuchen über

den Wärmeverbrauch an Koksöfen die Messungen unbedingt über mehrere Garungsperioden durchführen muss, da es keineswegs sicher ist, dass die Temperaturen des Mauerwerks der Batterie am Schluss der Messungen dem Anfangszustand bei Beginn der Messungen entsprechen.

Für die Grösse der Speicherung bezw. Entspeicherung während einer Garungsperiode wurden Werte gefunden, die für die gesamte Kokskammer bis zur Grössenordnung von 1 Million kcal/Garungsperiode herangehen. So wurde beispielsweise bei einem Versuch festgestellt, dass die Speicherung rd 17 500 kcal/m² während einer Garungsperiode betrug. Für die Höhe dieses Betrages ergibt sich ein Masstab daraus, dass während des gleichen Versuches der Heizfläche im Mittel nur 3 300 kcal/m² und Stunde während der ganzen Garungsperiode zugeführt wurden.

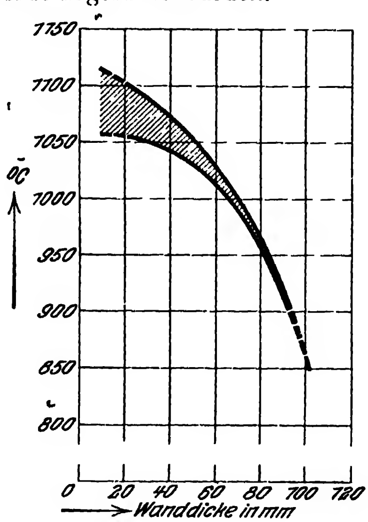

Abb. 4.—Speicherungsvorgänge während einer Umstellperiode in Abhängigkeit von der Wanddicke.

Zergliedert man den mittleren Wärmefluss, wie er in Abb. 2 wiedergegeben ist, nach den einzelnen Höhenlagen der Wand, entsprechend den Lagen der eingebauten Thermoelemente (vergl. Abb. 3), so zeigt sich, dass unten der Wärmefluss am stärksten war, während die höchsten Stellen der Wand. in Höhe des Horizontalkanales, nur noch geringe Mengen übertrugen. Es ist nicht uninteressant, dass oben in der Wand sogar gelegentlich ein *Wärmerückfluss* erfolgen kann. Abb. 5 zeigt einen solchen Fall, der allerdings in dieser Schärfe nur ein einziges Mal beobachtet wurde. also nicht verallgemeinert werden darf.

Aus Abb. 5 ergeben sich 5 verschiedene Arten von Flächen:

(*a*) Wärmefluss aus dem Heizzug in den Koks,
(*b*) Wärmefluss aus der Wand in den Koks (Entspeicherung),
(*c*) Wärmefluss aus dem Heizzug in die Wand (Speicherung),
(*d*) Wärmefluss aus dem Koks in die Wand (Speicherung),
(*e*) Wärmefluss aus dem Koks in den Heizzug.

Es sind also an dieser Stelle tatsächlich Wärmemengen aus dem Koks zur Aufheizung des Gases im Horizontalkanal (entgegen dem normalen Wärmefluss) durch die Wand gewandert.

Wiedergegeben sind in Abb. 5 auch noch die mittlere Oberflächentemperatur der Wand am Heizzug (Kurve 3) sowie das Mittel der Temperatur über die Wanddicke (Kurve 4), beides gültig für die Höhenlage in der die Thermoelemente eingebaut sind.

Einen Vergleich zwischen dem Wärmefluss bei Silikawänden und bei Schamottewänden erlaubt Abb. 6. Die höhere Wärmeübertragung der Silikabatterie entspricht der höheren Wärmeleitfähigkeit dieses Materials und bedingt damit die um etwa 25 % kürzere Garungszeit.

(C) Folgerungen.—Die Abb. 3, 5 und 6 zeigen, wie notwendig eine gleichmässige Zuführung der Wärme an die Heizzüge ist, wie sehr man also darauf achten muss, das Produkt aus Heizwert und Gasmenge für die Beheizung jedes Ofens konstant zu halten. Abb. 7 gibt eine Einzelheit der vorgenommenen Messungen wieder, und zwar unter Ausschaltung der Temperaturschwankungen, die durch die Umstellperiode hervorgerufen wurden, ferner unter Ausschaltung der laufenden Steigerung der Wandtemperatur während einer Garungsperiode. Hier ist der Verlauf der Temperatur des Elementes 8 (vergl. Abb. 3) aufgezeichnet und zugleich auch die Kurve des Produkts von Heizwert × Gasmenge des Heizgases, und zwar für einen kürzeren herausgegriffenen Zeitabschnitt. Der gleichsinnige Verlauf der beiden Kurven ist augenfällig. Derartiges könnte mehrfach festgestellt werden.

Weiter wird man die Forderung einer ständigen Temperaturüberwachung aller Heizzüge, wie sie heute auf allen gutgeleiteten Kokereien üblich ist, unterstreichen müssen. Nur auf diese Weise kann man einen gleichmässigen Wärmefluss erreichen. Während der Versuche war absichtlich auf eine *besondere* Temperaturüberwachung verzichtet worden.

Drittens wäre die Frage zu prüfen, ob es nicht möglich sein könnte, die Wandtemperatur im Heizzug während der ganzen Garungsperiode konstant zu halten. Abb. 8 zeigt ein Beispiel dafür, wie sehr die Temperatur in der Wand am Anfang der Garungsperiode abfallen kann. Durch eine Regelung der Gasmenge könnte die Temperatur auf annähernd gleicher Höhe gehalten werden, und in Abb. 9 ist ein Versuch dargestellt, bei welchem die Temperaturen in diesem Sinne geregelt wurden. Der Erfolg war eine Abkürzung der Garungszeit um 12,5 % bei gleicher Güte des Kokses.

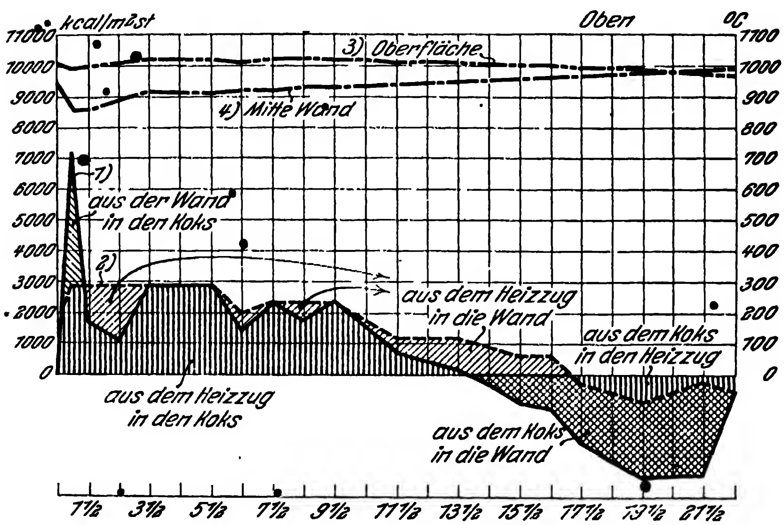

Abb. 5.—Ungewöhnliche Wärmeübertragung an der obersten Messtelle (Schamottebatterie).

Kurve 1: an den Koks abgegebene Wärme.
„ 2: vom Heizzug auf die Wand übertragene Wärme.
„ 3: mittlere Oberflächentemperatur der Wand.
„ 4: mittlere Wandtemperatur.

Viertens ergaben die Versuche, wie notwendig es ist, Messungen über den Wärmeverbrauch an Koksöfen stets über mehrere Perioden auszudehnen, damit sich die Einflüsse etwaiger Speicherungen und Entspeicherungen des Mauerwerks über die ganze Garungsperiode hin genommen, mildern.

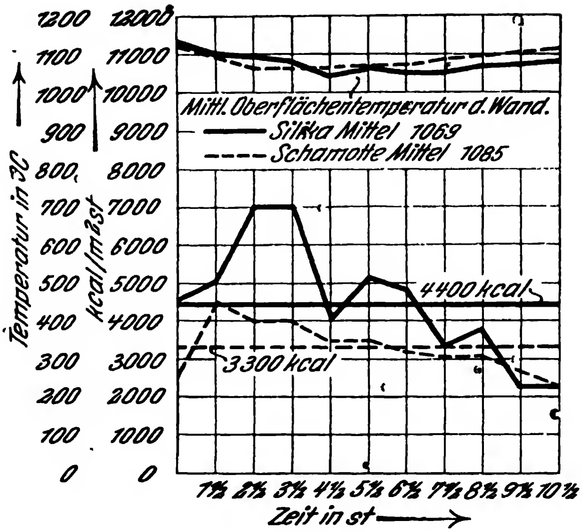

Abb. 6.—Vergleich des Wärmeflusses in den ersten Garungsstunden zwischen Schamotte- und Silikawänden.

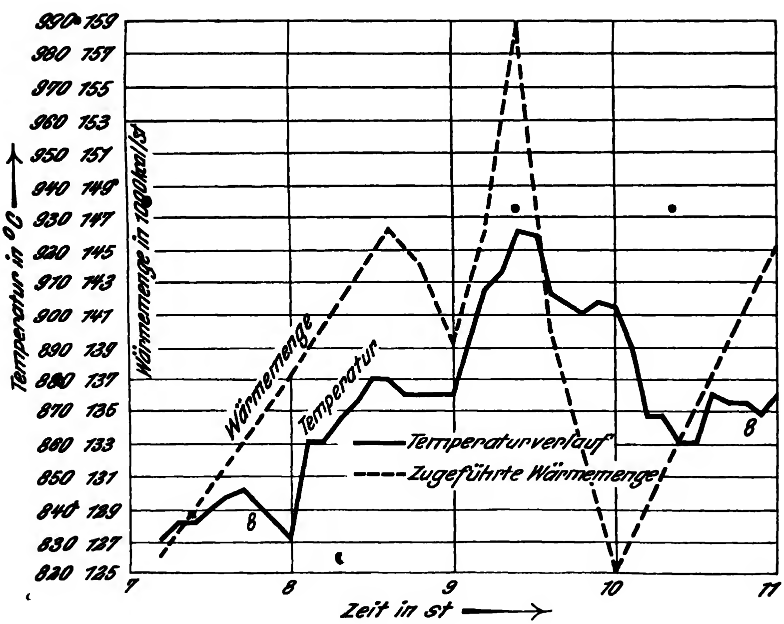

Abb. 7.—Zusammenhang zwischen der Beheizung und dem Wärmefluss.

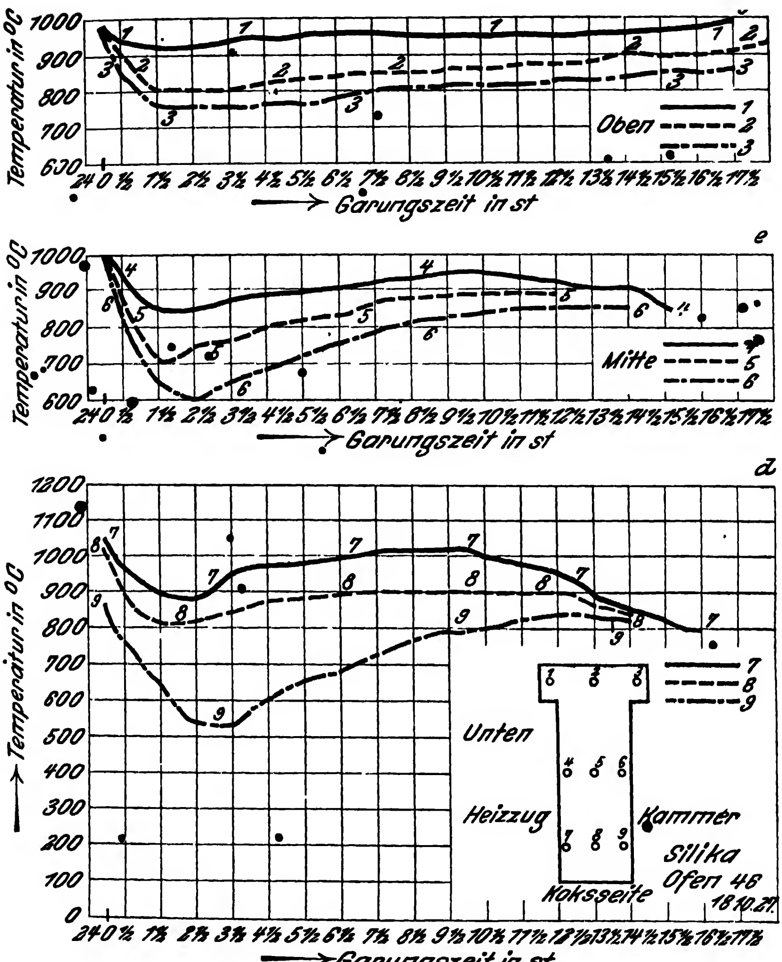

Abb. 8.—Abfall der Temperaturen am Anfang der Garungsperiode bei gewöhnlicher Beheizung.

(D) Die Nutzwärme.[4]—Die nachstehende Übersicht gibt eine Zergliederung der gesamten Wärme wieder, teilt also die rechte Seite der Wärmebilanz in einzelne Posten auf.

[4] Die in diesem und dem nachfolgenden Abschnitt wiedergegebenen Erörterungen beruhen zum grossen Teil auf Untersuchungen von Dipl.-Ing. Oestrich, die dieser im Auftrage der Wärmestelle des Vereins deutscher Eisenhüttenleute durchgeführt hat.

Gesamte Wärme

- (I) Nutzwärme
  - (1) Wasseraustreibung
    - (*a*) Verdampfung
    - (*b*) Überhitzung
  - (2) Verkokung
    - (*a*) Mindestverkokungswärme
      - (α) fühlbare Wärme des Kokses
      - (β) fühlbare Wärme des Gases
      - (γ) Spaltungswärme
    - (*b*) Übergarungswärme
      - (α) Erhöhung der fühlbaren Wärme des Kokses
      - (β) Erhöhung der fühlbaren Wärme des Gases
      - (γ) zusätzliche Spaltungswärme
  - (3) Gasüberhitzung
    - (*a*) fühlbare Wärme
    - (*b*) Spaltungswärme
- (II) Abgasverlust
- (III) Strahlung und Leitung

Zu den hier angeführten Begriffen sei folgendes bemerkt:

(I) *Nutzwärme* (hierzu vergleiche Abschnitt (A) dieser Arbeit).

In der Nutzwärme sind sowohl Einflüsse der Ofengüte nach Bauart und Zustand, wie der Betriebsführung, wie schliesslich der verwendeten Kohle enthalten; diese Einflussgruppen voneinander zu

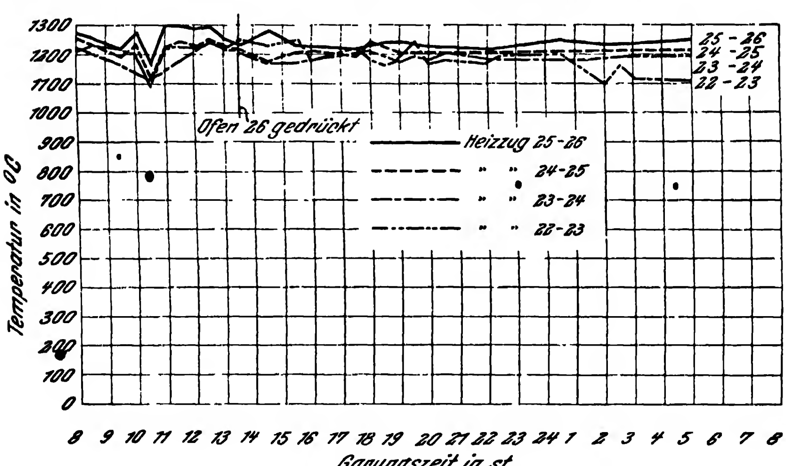

Abb. 9.—Versuch mit geregelten Temperaturen; gemessene Düsentemperaturen.

trennen, ist sehr schwierig; die Verhältnisse liegen indessen in dieser Beziehung nicht anders als bei jedem anderen Ofen oder auch beim Dampfkessel; auch hier kann man z.B. eine Prüfung der Ofengüte, z.B. eine Nachprüfung von Garantiebedingungen, nur vornehmen,

indem man eine bestimmte, möglichst hohe Güte der Betriebsführung annimmt und einen ganz bestimmten Brennstoff voraussetzt. Will man andererseits durch praktischen Versuch am Koksofen die Verschiedenheit des Wärmebedarfs verschiedener Kohlen feststellen, so muss man die Versuche am gleichen Ofen bei gleichem Zustand desselben und mit gleicher Güte der Betriebsführung vornehmen.

Die Nutzwärme, d.h. die praktisch zur Durchführung des Arbeitsprozesses erforderliche Wärme, ist unterteilt in (1) Wasseraustreibung, (2) Verkokung und (3) Gasüberhitzung. Der Wärmeaufwand für Verkokung und Gasüberhitzung stellt den Nutzwärmebedarf der trockenen Kohle dar; er ist eine wichtige Vergleichszahl, deren Messung weiter unten besprochen werden soll.

(1) *Wasseraustreibung.*—Zur praktischen Durchführung der Verkokung im Koksofen muss zunächst das Wasser verdampft werden; die Wasserdämpfe entweichen mit einer dem Druck in der Kammer entsprechenden Temperatur von rund 100°C, steigen im Innern der Beschickung (durch die Teernaht abgetrennt) auf und überhitzen sich hierbei. Über der Beschickung mischen sie sich mit den auf der anderen Seite der Teernaht aufgestiegenen heissen Gasen; die Mischung ist den Einflüssen der Wandtemperaturen des Raumes, in dem sie sich zum Gasabzug bewegen, ausgesetzt. Es ist unbekannt, wie hoch sich die Wasserdämpfe überhitzen, bevor sie die Beschickung verlassen. Für die Bestimmung der zur Wasseraustreibung erforderlichen Wärme müssen wir aber eine Überhitzungstemperatur annehmen. Rechnen wir mangels besserer Unterlagen mit etwa 150°C, so sind je kg Wasser zur Austreibung 670 kcal erforderlich. Die Umrechnung der Nutzwärme von nasser Kohle auf trockene Kohle erfolgt nach dem Ansatz:

a kg trockene Kohle . y kcal je kg trockene Kohle $+$ b kg Wasser . 670
$=$ $(a + b)$ kg nasse Kohle . x kcal je kg nasse Kohle. (Näheres siehe Mitteilung Nr. 106 der Wärmestelle des Vereins deutscher Eisenhüttenleute, Düsseldorf.) Der für jeden der drei Posten aufzuwendende Anteil an der *Gesamt*wärme ergibt sich, indem man y, 670 und x mit dem Faktor $\frac{\text{Gesamtwärme}}{\text{Nutzwärme}} = \frac{1}{\eta}$ multipliziert.

(2) *Die Verkokungswärme* trennen wir in

(*a*) Mindestverkokungswärme,

(*b*) Übergarungswärme.

Die Übergarungswärme würde gleich 0 werden, wenn es möglich wäre, den ganzen Kokskuchen gleichzeitig auf die Endtemperatur der Verkokung zu bringen. Da dies nicht möglich ist, muss ein Mehr an Wärme aufgewendet werden, das sich in örtlichen Überhitzungen des Kokskuchens äussert.

Die Wärmemenge, die zur Übergarung notwendig ist, spielt nur dann im Rahmen der Wärmebilanz eine nennenswerte Rolle, wenn bei der "Überhitzung" des Kokses starke endotherme Zersetzungen auftreten. Dies kann allerdings der Fall sein. Beispielsweise haben E. Terres und H. Wolter[1] für die Kohle der Zeche Zollverein in Westfalen durch Laboratoriumsmessungen festgestellt, dass bei der Erhitzung des Kokses von 1 000 auf 1 050°C ein Mehrwärmeaufwand von 80 kcal/kg (!) trockene Kohle auftritt. Die für die Spaltung aufgewandte Wärme findet sich in einer Erhöhung des Heizwertes von Koks und Gas wieder, die bei Spaltung verbrauchte Wärme in einer entsprechenden Erniedrigung.

Der Einfluss des für die Übergarung notwendigen Zeitaufwandes auf die Höhe der Strahlungs- und Leitungsverluste je t Koks ist gering. Wird durch die notwendige Übergarung die Garungsdauer um 10% gesteigert, und betragen die Strahlungs- und Leitungsverluste in der Bilanz 6%, so macht die Erhöhung der Strahlungs- und Leitungsverluste durch die Übergarung $0{,}1 \times 6 = 0{,}6\%$ in der Bilanz aus. Man überschätzt diesen Einfluss leicht und hält den grössten Teil der während der Übergarungszeit im Heizzug aufgewandten Wärme für verloren, während diese Wärme in Wirklichkeit bei richtiger Beheizung zur Aufspeicherung des Mauerwerks verwandt und später wieder abgegeben wird. Der Vorteil geringer Übergarungszeit, wie er z.B. bei engen Kokskammern gegeben ist, liegt in der kürzeren Garungsdauer und der dadurch erreichten Steigerung des Durchsatzes je m^2 Heizfläche und Stunde. Diese Steigerung des Durchsatzes bezieht sich sowohl auf die durch die Kammer durchgesetzte Kohlen- bezw. Koksmenge, als auch auf die durch den Heizzug und die Wand stündlich durchgesetzte Wärmemenge, letzteres deshalb, weil bei geringerer Übergarungszeit das Temperaturgefälle zwischen der Wand der Kokskammer und der Mitte des Kokskuchens kleiner und daher (bei gleicher Temperatur der Heizfläche an der Wand des Heizzuges) das Temperaturgefälle in der Wand

[1] "Über die Verkokungswärme von Gas- und Kokskohlen" Gas- und Wasserfach 70 (1927) Heft 1-4

grösser wird und damit mehr Wärme durch die Wand fliesst. Bei engen Kammern wird die Garungszeit in der Hauptsache dadurch verkürzt, dass je m^3 Kammerinhalt ein grösserer Heizgasdurchsatz erzielt wird, da die auf 1 m^3 entfallende Kammerheizfläche grösser wird.

Zieht man die Übergarungswärme von der Verkokungswärme ab, bezw. ist, wie beim Laboratoriumsversuch der Verkokung im Tiegel, die Übergarungswärme gleich Null, so bleibt die "Mindestverkokungswärme" übrig. Sie ist diejenige Wärmemenge, die erforderlich ist, um den Koks auf die Endtemperatur zu bringen und das Gas jeweilig auf die Temperatur, bei der es gebildet wird. Sie setzt sich zusammen:

(α) aus der fühlbaren Wärme des Kokses bei der Endtemperatur der Verkokung,

(β) aus der fühlbaren Wärme des Gases, jeweilig bis zur Temperatur, bei der das Gas gebildet wird, wobei vorausgesetzt wird, dass es mit dieser Temperatur entweicht,

(γ) aus der Spaltungswärme, wobei unter dem Begriff "Spaltungswärme" zunächst alle wärmeerzeugenden und wärmebindenden Vorgänge zusammengefasst sein mögen, die bei der Verwandlung der trockenen Kohle von der Einsatztemperatur in Koks und Gas von der Endtemperatur (siehe oben unter α und β) vor sich gehen, also einschliesslich der latenten Wärmen bei Übergang eines Aggregatzustandes in einen andern.

(3) Die *Gasüberhitzung*, die beim praktischen Betriebe im Koksofen dadurch eintritt, dass die Gase nicht mit ihrer Bildungstemperatur entweichen können, sondern sich beim Aufsteigen durch den heissen Koks erhitzen, sind in vorstehenden Ausführungen nicht zur "Verkokungswärme" gerechnet, da die Verkokung auch ohne die Überhitzung der Gase stattfinden kann. Die zur Überhitzung nötigen Wärmemengen müssen also als besonderer Bestandteil der Nutzwärme angeführt werden. Hier können gleichfalls noch Spaltungsprozesse eintreten; über deren Höhe wissen wir vorläufig nichts, und wir müssen sie daher einstweilen vernachlässigen Auch eine Berechnung der fühlbaren Wärme der Gasüberhitzung können wir nicht vornehmen, schon deshalb, weil wir Menge und Zusammensetzung der bei den einzelnen Temperaturen entweichenden Gase nicht kennen. Die Endtemperatur der Gase wird beim Verlassen des Kokskuchens etwa dessen Temperatur erreichen. Durch Vermischen mit dem auf der anderen Seite der

Koksnaht aufsteigenden Wasserdampf wird die Temperatur der Gase wieder heruntergesetzt (Vergl. die Ausführungen unter 1).

Bezüglich der Spaltungswärme der Kohle liegen bereits einzelne Untersuchungen vor.[6]

Diese Untersuchungen zeigen, dass bei verschiedenen Kohlen sehr verschiedene Spaltungswärmen auftreten. Z.B. stellten Terres und Wolter fest, dass für die untersuchten westfälischen Kohlen die Spaltungswärmen etwa zwischen + 40 und — 120 kcal/kg Kohle liegen und anscheinend weisen andere Kohlen noch erheblich stärkere Schwankungen auf. *Es handelt sich jedenfalls um Zahlen, die bei der Aufstellung der Bilanz keineswegs vernachlässigt werden dürfen.* Bereits auf Grund der von Terres und Wolter angegebenen Zahlen errechnen sich Mindestverkokungswärmen, die zwischen 286 und 438 kcal/kg Kohle liegen.

(E) Folgerungen für die Gewährleistungen des Ofenerbauers und für den Betrieb.—Im vorigen Abschnitt wurde ausgeführt, dass die Mindestverkokungswärme je nach der Art der Kohle stark wechselt. Ohne die Kenntnis dieser Verkokungswärme ist es daher nicht möglich, eine Gewährleistung des Ofenerbauers für den Wärmebedarf seines Ofens je kg Kohle zu verlangen, oder Zahlen des Wärmebedarfs je kg Koks bei verschiedener Kohle als Masstab für die Güte des Ofens oder des Betriebes zugrunde zu legen. Ferner ist es ebenso unmöglich, ohne Kenntnis der Verkokungswärme eine Gewährleistung der Erzeugungshöhe oder der Garungszeit zu verlangen, oder diese Zahlen als Vergleichsmasstab für mit verschiedenen Kohlen betriebene Öfen zu betrachten. Die vorstehenden Erörterungen stehen im Gegensatz zu den bisher üblichen Anschauungen.

Eine Bestimmung der Mindestverkokungswärme für die verschiedenen Kohlensorten ist zwar laboratoriumsmässig möglich, die Untersuchung ist aber sehr schwierig, ganz abgesehen davon, dass eine betriebsbrauchbare Versuchseinrichtung noch geschaffen werden müsste.

Aber auch dann würde man noch nicht die Gewissheit haben, dass das gewonnene Ergebnis die Mindestverkokungswärme für die Verarbeitung im Koksofen darstellt. Denn im Koksofen ist die Führung des Verkokungsprozesses anders als in der Versuchsanstalt, z.B. dauert der Vorgang viele Stunden anstelle von Minuten.

[6] E. Terres und A. Schaller, Gas- und Wasserfach 65 (1922) S.762. J. Davis, Fuel 4 (1925) S.286. Burke and Parry, Ind. Engg. Chem. 19 (1927) S.15. E. Terres und H. Wolter, Gas und Wasserfach 70 (1927) S.1/5, 30/5, 53/8 und 81/5.

Aber selbst wenn die Mindestverkokungswärme bei einer bestimmten Temperatur genau genug festgestellt werden könnte, so müsste man doch noch nachprüfen, ob wirklich die dieser Verkokungswärme entsprechende Mindesttemperatur an allen Stellen des Kuchens erreicht würde. Es hat sich beispielsweise gezeigt, dass infolge verschieden starker Ausgarung des Kokses bei demselben Ofen und denselben Kohlen Unterschiede im Wärmeverbrauch von 150 kcal/kg Kohle auftraten.[7]

Angesichts dieser Schwierigkeiten dürfte es empfehlenswert sein, die Beurteilung der Ofengüte nicht auf der Abweichung der im Heizgas aufgewandten Wärme von der Mindestverkokungswärme aufzubauen, wie dies etwa in dem Faktor

$$\frac{\text{Mindestverkokungswärme}}{\text{Heizgaswärme}}$$

zum Ausdruck kommen könnte.

Dagegen bietet sich eine andere Möglichkeit:

Der Faktor

$$\frac{\text{Nutzwärme}}{\text{Heizgaswärme}}$$

ist zur Beurteilung der Ofengüte und damit auch zum Aufbau von Garantien vortrefflich geeignet.

Die Heizgaswärme kann gemessen werden.

Die Nutzwärme kann bestimmt werden aus der Gleichung (vgl. die Bilanz in Abschnitt A): Nutzwärme = insgesamt eingebrachte Wärme – Abgasverlust —Strahlung und Leitung.

(*a*) Die insgesamt eingebrachte Wärme setzen wir in erster Annäherung der Heizgaswärme gleich, doch kann auch die in der fühlbaren Wärme der Luft und der Kohle eingebrachte Wärme für genauere Rechnungen ohne weiteres mit berücksichtigt werden.

Eine weitere Bestimmung der Nutzwärme, die als Kontrolle vorstehender Rechnung benutzt werden kann, ergibt sich aus folgender Betrachtung, auf die G. Neumann den Verfasser aufmerksam machte. Aus einem Vergleich der Bilanzen I und II im Teil A dieser Arbeit kann man durch Subtraktion der Bilanz I von der Bilanz II die Bilanz III ableiten:

[7] Nach bisher nicht veröffentlichten Abnahmeversuchen des Dampfkessel-Überwachungsvereins der Zechen im Oberbergamtsbezirk Dortmund, Essen.

BILANZ III.

I	Heizwert der eingesetzten Kohle ...	kcal	I	Heizwert des Kohles ...	kcal
II	Nutzwärme ...	„	II	Heizwert ausgebrachten Gases ...	„
			III	Fühlbare Wärme des Kokses ...	„
			IV	Fühlbare Wärme des ausgebrachten Koksgases	„
			V	Latente und fühlbare Wärme des Wasserdampfes	„
	Summe ...	kcal =		Summe ...	kcal

Die Nutzwärme ist also gleich der Differenz des Wärmeinhalts der eingebrachten Kohle und der ausgebrachten Verkokungsprodukte.

Hieraus ergibt sich—freilich mit allen Fehlern, die einer Differenzmethode grosser Beträge anhaften und mit allen Unsicherheiten der Bestimmung richtiger Durchschnittswerte—die Möglichkeit, die Nutzwärme zu errechnen.

(*b*) Der Abgasverlust kann aus Abgasmenge und Abgastemperatur berechnet werden, am besten, indem die Abgasmenge gemessen wird. Will oder kann man nicht messen, so muss sie in der üblichen Weise berechnet werden.

Die Strahlung und Leitung kann mit genügender Sicherheit bestimmt werden, wenn man die Temperaturen der Aussenwand der Ofenbatterie abtastet. Die Strahlungs- und Leitungsverluste unterteilt man am besten in die Verluste des Oberofens und die des Unterofens. Für den Oberofen ermittelt man sie aus der Übergangsgleichung.

$$Q = \beta \cdot F\ (t_1 - t_2)$$

Der Wert β enthält den Einfluss der Konvektion (α) und der Strahlung (α_s)

$$= \alpha + \alpha_s{}^{8}$$

Man untersucht die Strahlungsverluste am besten bei ruhigem, trockenem Wetter und bedecktem Himmel, da für diese Verhältnisse die Wärmeübergangszahl am besten bekannt ist. Die Wärmeverluste sind von der Witterung nicht sehr abhängig. Das kommt daher, dass der Hauptwiderstand für den Wärmedurchgang im Mauerwerk selbst liegt, d.h., dass die Wärmedurchgangszahl k in

[8] Werte für α und α_s sowie Rechnungsbeispiel, siehe Mitteilung Nr. 51 der Wärmestelle des Vereins deutscher Eisenhüttenleute, Düsseldorf (1923) S.17.

$$Q = k\ F\ (t_1 - t)$$

$$k = \frac{1}{\frac{1}{\beta} + \frac{\lambda}{\delta} + \frac{1}{\beta_1}}$$

in der Hauptsache von dem Wärmewiderstand des Mauerwerks $\frac{\lambda}{\delta}$ und dem Wärmeübergangswiderstand im Inneren des Ofens $\frac{1}{\beta_1}$ beeinflusst wird. Die Wärmeverluste sind deshalb bei Regen oder Windanfall nur in der Grössenordnung von 10% höher.

Den Strahlungsverlust des Unterofens bestimmt man durch Oberflächentemperaturmessung an den Regeneratorwänden in den Begehkanälen. Man muss aber bei der Berechnung beachten, dass hier die Temperatur der gegenüberliegenden Wand höher ist als die Temperatur der Umgebung bei Abstrahlung ins Freie. In einfacher Weise kann man mit einem Wärmeflussmesser für verschiedene Wandtemperaturen den Wärmeverlust je m² und st bestimmen.

Da der Ofenwirkungsgrad $= \frac{\text{Nutzwärme}}{\text{zugeführte Wärme}}$ ist, kann man diesen Wirkungsgrad beim Abnahmeversuch bestimmen. *Er ist demnach eine Grösse, die man sich von dem Erbauer des Ofens gewährleisten lassen kann.* Dies ist aber auch die einzige Gewährleistung, die er für die Güte der Feuerung übernehmen kann. Er kann nichts weiter tun, als die Wärme an die Ofenwand heranzubringen, und möglichst viel von dieser Wärme durch die Wand an den Koks zu leiten.

Beim Koksofen kommt es nicht nur auf den Wärmeverbrauch an, sondern auch auf die Höhe der Erzeugung. Es ist bisher üblich, für Oefen eine bestimmte Garungszeit anzugeben. Die Garungszeit ist aber nicht nur abhängig von der Güte der Oefen, sondern auch, genau wie der Wärmeverbrauch je kg Kohle, von der verarbeiteten Kohlensorte. Jede Wärmeübertragung erfordert Zeit. Da schon die trockenen Kohlen eine sehr verschiedene Verkokungswärme besitzen, so kann man nicht verlangen, dass alle Kohlen in der gleichen Zeit verkokt werden. Wenn man auch für den verschiedenen Nässegehalt eine Reduktionsformel auf trockene Kohle finden kann, so bleibt das für die verschiedenen Verkokungswärmen solange unmöglich, als sie nicht bekannt sind.

Man kann aber sagen, dass die Garungszeit um so geringer wird, je mehr Wärme man stündlich in die Kammer bringt, d.h. je mehr Heizgas man stündlich mit einem bestimmten Wirkungsgrad verfeuert. Kohlensorten, die mit Rücksicht auf die Herstellung einer besonderen Koksgüte mit besonders schwacher Beheizung verkokt werden, haben dementsprechend eine längere Garungszeit. Bei allen anderen Kohlensorten ist die stündlich in die Kokskammer übertragene Wärme durch die höchst zulässige Temperatur begrenzt, die das Mauerwerk aushalten kann.

Es kommt deshalb darauf an, dass eine bestimmte Heizgasmenge stündlich verfeuert werden kann. Man kann daher vom Erbauer einen bestimmten Durchsatz an Heizgas gewährleisten lassen unter der gleichzeitigen Bedingung, dass eine bestimmte zu verabredende Wandtemperatur nicht überschritten wird.

Nun kann aber bei einer bestimmten Temperatur der Heizzüge oder bei einem bestimmten Durchsatz an Heizgas für eine gegebene Kohle mit gegebener Nässe die Garungszeit noch verschieden sein, weil die Übergarungswärme verschieden ist. Sieht man davon ab, dass eine ungeschickte Betriebsführung die Übergarungswärme unnötig erhöhen kann, so liegt die Kunst des Ofenbauers darin, die Wand so gleichmässig zu beheizen und die Abmessungen der Kammern und der Wände so zu wählen, dass eine möglichst geringe Übergarungswärme verbraucht wird. Sie ist um so geringer, je gleichmässiger die Temperaturen am Ende der Garungszeit im Kuchen sind.

Die Gleichmässigkeit der Temperaturen innerhalb des Kokskuchens lässt sich beim Abnahmeversuch messen und in die Form einer Garantie kleiden, z.B., dass, wenn an einem bestimmten Punkte der Mittelebene eine Temperatur von 1 000°C erreicht ist, an bestimmten anderen Punkten der Mittelebene eine gewisse Mindesttemperatur herrschen muss.

Es können also folgende Garantien verlangt werden:

1. guter Ofenwirkungsgrad;
2. hoher Durchsatz an Heizgas je st und m^3 Kammerinhalt bei bestimmter Wandtemperatur;
3. geringfügige Temperaturunterschiede in der Mittelebene des Kokskuchens.

Als Kennziffer kommt hinzu die Heizfläche je m^3 nutzbarer Kammerinhalt.

Für den Abnahmeversuch sind eine Reihe von besonderen Bestimmungen zu treffen. So z.B. muss dessen Dauer festgelegt werden. Er muss sich zur Verwischung des Einflusses von Speicherungen im Mauerwerk auf mindestens drei Garungsperioden erstrecken. Ein Temperaturunterschied von 50°C im gesamten Mauerwerk von rd. 50 t je Ofen bedeutet in der Garungsperiode einen Fehler von etwa 70 kcal/kg eingesetzte nasse Kohle!

Ferner muss z.B. festgelegt werden, ob die Abgastemperatur mit Absaugepyrometer, ob die Temperaturen in den Zügen mit Thermoelement gemessen werden sollen, an welchen Stellen die Temperaturen zu messen sind (Fuchsende, Horizontalkanal bezw. abziehende senkrechte Heizzüge, dieses zur Vermeidung von Fehlern durch Flammenstrahlung bei Thermoelementen), wie und bei welchen und bei wieviel Einzelöfen die Temperaturen im Kuchen zu bestimmen sind, Feststellung der Abgasanalyse durch Sammelproben, Art der Bestimmung der Strahlungs- und Leitungsverluste u. dgl. m.

Genau genommen müssten in die Bilanz des Koksofens noch Posten aufgenommen werden, die den Einfluss von Undichtheiten der Kammerwände berücksichtigen. Bei einer neuen Ofenbatterie, an der etwa ein Abnahmeversuch zu machen ist, können diese vernachlässigt werden, wenn der Druck zwischen der Kammer und den Heizzügen klein ist. Im laufenden Betrieb älterer Batterien werden sich jedoch leicht Undichtheiten einstellen, sodass die ohne Berücksichtigung der Undichtheiten ermittelte Bilanz in solchen Fällen nicht stimmt.

Der Einfluss von Undichtheiten sei im folgenden näher untersucht. Den wesentlichsten Einfluss haben undichte Heizwände. Tritt Koksgas aus den Kammern in die Heizzüge und verbrennt dort, so ergibt sich eine "fremde," in der Bilanz nicht gebuchte Wärmezufuhr. Bei der Bestimmung der Nutzwärme als Rest erscheint dieser Fehler als Verkleinerung der Nutzwärme und der berechnete Wirkungsgrad wird schlechter. Diese Undichtheiten erscheinen also als Verschlechterung des Ofenwirkungsgrades. Wenn das übergetretene Koksgas unvollständig oder zu spät verbrennt, wird der Wirkungsgrad infolge der Steigerung des Abgasverlustes noch schlechter.

Wenn Heizgas (Frischgas) durch Undichtheiten in die Kokskammer tritt, so wird der errechnete Wirkungsgrad höher. Indessen pflegen solche Undichtheitsverluste selten zu sein;

bei Schwachgasbatterien können Risse in der Bodenfläche der Kammer unter den herrschenden Druckverhältnissen Übertritt von Heizgas aus den Regeneratorkammern in die Kokskammer hervorrufen. Bei nennenswertem Übertritt von Frischgas muss bei gleichen Wandtemperaturen aber der Heizgasverbrauch je st steigen, der ein weiteres Kennzeichen für die Betriebsgüte ist. (Im Falle des zuerst erörterten Übertritts von Koksgas in die Heizkammer muss der stündliche Heizgasverbrauch fallen.) Im allgemeinen soll der Heizgasverbrauch gleichmässig sein. Undichtheiten im Horizontalzug äussern sich meist durch Flammen beim Austreten des Koksgases, und diese können beobachtet werden.

Die laufende Verzeichnung des Feuerungswirkungsgrades und des Heizgasverbrauches je m^2 Heizfläche oder je m^3 Kammerinhalt gibt also ein Bild über die Dichtheit der Wände. Daneben sind diese beiden Zahlen natürlich auch von der Güte des Betriebes, vor allem von der Gleichmässigkeit der Beheizung abhängig. Ändert sich der Wassergehalt der Kohle, oder ändert sich gar die Kohle selbst, sodass andere Spaltungswärmen auftreten, so muss sich der Wirkungsgrad gleichfalls ändern.

Auf alle Fälle sind Garungszeit, Feuerungswirkungsgrad und spezifischer Heizgasverbrauch, letzterer auf m^2 Heizfläche m^3 Kammerinhalt und erzeugte t Koks bezogen, Grössen, die in allen Überwachungsberichten von Kokereien als Kennzeichen auftreten müssten.

(F) ZUSAMMENFASSUNG.—Die Bedeutung der Wände des Koksofens als Heizfläche ist wesentlich; der Wärmefluss durch die Wand zeigt die nicht unbeträchtliche Grösse der Speicherung und Entspeicherung während der Umstellperioden und während der Garungsperioden. Die Speicherung während der Umstellperiode bewegt sich in Grössenordnungen von etwa 500 kcal je Periode und m^2 Heizfläche. Die Speicherung während der Garungsperiode wurde bei den Messungen bis zu Grössen von etwa 17 500 kcal je Garungsperiode und m^2 Heizfläche festgestellt. Die gesamte Wärmezufuhr betrug bei dieser Speicherung etwa 3 300 kcal/st und m^2 Heizfläche. Es handelt sich also um beträchtliche Werte. Festgestellt wurde auch, dass die Speicherung während einer Garungsperiode durchaus nicht immer gleich der Entspeicherung während derselben Periode ist. Es wurde z.B. errechnet, dass bei einer der Messungen etwa 150% derjenigen Wärme gespeichert wurde, welche im Anfang der gleichen Garungsperiode entspeichert

worden waren. Der Wärmefluss in die Wand selbst war sehr unregelmässig. Das Gleiche gilt für den Wärmefluss an den Koks. Alles dies zwingt zu einer genauen Temperaturüberwachung, die während der Versuche absichtlich nicht durchgeführt worden war. Vielmehr hatte man es dem Aufsichtspersonal überlassen, die Batterie so einzustellen, wie es ihm zweckmässig erschienen war.

Die Aufstellung einer Wärmebilanz führt zunächst zu einer kennzeichnenden Unterteilung der durch die Wand geflossenen Wärmemenge nach ihrer Verwendung. Der eigentliche Bedarf der Verkokung, die "Mindestverkokungswärme," ist sehr stark von den chemischen Reaktionen während der Verkokung abhängig. Dies führt zu der weiteren Folgerung, dass es unmöglich ist, die Güte eines Koksofens nach dem Aufwand je kg eingesetzte Kohle oder je erzeugtes kg Koks zu beurteilen, wenn man die endotherme oder exotherme Spaltungswärme der betreffenden Kohle nicht kennt. Ebenso hängt die Dauer der Garungszeit von der Höhe dieser Spaltungswärme ab.

Mit Hülfe der neuen Methoden der Messtechnik ist man in der Lage, die Nutzwärme der Verkokung, welche ungefähr der durch die Heizwand gehenden Wärmemenge gleich ist, aus der Bilanz zu errechnen. Dividiert man die Nutzwärme durch die insgesamt aufgewandte Wärme, so erhält man den Ofenwirkungsgrad, der als wichtiges Kennzeichen für die Güte des Ofens und des Betriebes anzusprechen ist. Daneben wird die Höhe des Heizgasdurchsatzes je m^2 Heizfläche als wichtige Kennziffer eingeführt. Auch der Wert Heizgasdurchsatz je m^3 Ofeninhalt kann für Vergleichszwecke von Wichtigkeit sein. Von Bedeutung ist schliesslich die Gleichmässigkeit der Abgarung über den ganzen Kammerinhalt, die durch Messung der Temperaturen im Kokskuchen festgestellt werden kann.

HEAT TRANSFER THROUGH THE WALLS OF COKE OVENS

K. RUMMEL

(English Translation)

(A) The Importance of the Heating Surface.—The wall between the heating flues and the coking chamber forms the "heating surface" of the coke oven. The heating surface per oven may be expressed by means of the formula:—Heating surface, $F = 2$ (length of oven, B. $\times$ heated elevation, H.) In the case of vertical heating flues, H can be taken as the distance from the lower edge of the sole of the flue to the upper edge of the horizontal flue.

As in the case of steam boilers, the capacity, L, can be expressed in the form of production per square metre of heating surface per hour. Thus, the capacity of coke ovens can be defined in terms of the number of metric tons

of coke produced per square metre of heating surface per hour. A more exact figure, which is more suitable for many purposes, is the capacity, Q_n, expressed as kilogramme-calories of "effective" heat transmitted per square metre of heating surface per hour. It changes progressively during the course of carbonisation. If, further, a quantity of heat, Q_b, be supplied to the oven per square metre of heating surface (Q_b being equal to the calorific value of the fuel gas × the quantity of gas per square metre) the efficiency of the oven, E, will be represented by the fraction $\frac{Q_n}{Q_b}$.

The heat balance of the oven may be formulated as follows:—

HEAT BALANCE I. (Process balance.)

Origin of heat	Kilogramme calories.	Utilisation of heat.	Kilogramme calories.
I. From the heating gas..		I. Effective heat ($Q_n \cdot F$)	
II. From the sensible heat of the combustion air...		II. Loss in flue gases ...	
III. From the *sensible* heat of the coal charge (*not* its calorific value) ...		III Losses by radiation and conduction	
Total ...		Total	

For strict accuracy a small correction should be made to Item I. on the right-hand side, since the total heat flow through the wall of a boiler or coke oven is not identical with the amount described above as "effective" heat, for a portion of the heat lost by radiation and conduction in the coke oven is actually derived from the heat contained in the coking chamber, and this heat is also conveyed to the coking chamber through the wall. To this extent the heat flow through the wall is not absolutely equal to the "effective" heat, but the error is not large. If it be assumed that the total losses by radiation and conduction amount to about 6 per cent., and if the further assumption be made that one-third of this is lost by way of the oven bottom, a further third by way of the heating flues, and the remaining third by way of the coking chamber, the total error would amount to 2 per cent. The following equation takes this 2 per cent. into account :—

"Effective" heat = (Heat passed through the oven wall)—(One-third of the losses by radiation and conduction).

The arithmetical evaluation of this equation leads to no difficulties, since, as is shown below, the losses by radiation and conduction can be determined with sufficient exactitude, and it is, therefore, unnecessary, as has hitherto been customary, to determine it by difference when the separate items of the heat balance[1] are added up.

It is immaterial whether all the items in the above heat balance are referred to one square metre of heating surface per hour, or to a single coking period,

[1] For details see Section E.

or to one cubic metre of fuel gas, or to 100 kilogramme calories of fuel gas. In the latter case, all the items in the heat balance are expressed as a percentage of the heat supplied by the gas used for heating the oven.

The above heat balance differs from the usual form of heat balance for coke ovens (Table II.), more particularly in the fact that the calorific value of the coal charge does not appear on the left-hand side of the balance:—

HEAT BALANCE II. (Combined material and heat balance.)

Origin of heat.	Kilogramme calories.	Utilisation of heat.	Kilogramme calories.
I. Calorific value of the coal charge		I. Calorific value of the coke	
II. Calorific value of the fuel gas...		II. Calorific value of the coke oven gas	
III. Sensible heat of the coal and the combustion air		III. Sensible heat of the coke and gas	
		IV. Latent and sensible heat of the water vapour ...	
		V. Loss in flue gases ...	
		VI. Losses through radiation and conduction ...	
Total... ...		Total	

Thus, in Heat Balance I. the coal is considered not as a fuel but as a raw material under treatment, just as is the iron in the case of a Siemens-Martin steel furnace. Thus Heat Balance I. is essentially a process balance. In the Siemens-Martin furnace a portion of the charge of iron is oxidised, and the heat evolved by such oxidisation is by no means unimportant in the heat balance, and has to appear in it. For all that, nobody would think of including in the heat balance the total amount of heat which would be obtained if the whole of the iron were oxidised in the furnace. In Heat Balance I. exactly the same considerations are applied to the coke oven.

Before considering this heat balance in detail, we will consider the manner in which heat flows through the oven wall.

(B) HEAT FLOW THROUGH THE OVEN WALL.[2]—When the coal is charged into the oven, the coal is cold and the oven hot. The surface temperature of the wall in immediate contact with the coal consequently drops to a value which may be but little higher than 100°C., the boiling point of the water introduced with the coal, and then immediately rises once more. The rise of temperature is at first rapid, and then slower, but it continues almost to the end of the carbonising period. When the wall is cooled, a portion of its

[2] The experiments described below were carried out by Dipl. Engineer Steinschlager at a colliery in the Rhenish Westphalian coalfield, on behalf of the Fuel Laboratory of the Verein deutscher Eisenhüttenleute.

heat content is removed. Subsequently, during the course of the carbonising period, heat is again stored up in the wall. According to the above considerations, transmission of heat from the wall to the coke must take place in the manner shown diagrammatically in Fig. 1, Curve 1. During heat storage the temperature of the flue side of the heating wall falls; therefore at the commencement of the carbonising period more heat is transferred from the heating flue to the wall than at the end of the coking period; therefore the transmission of heat from the heating flue to the wall must proceed as is shown diagrammatically in Curve II., Fig. 1, in which area A indicates supply of heat from the wall, and area B, storage of heat in the wall.

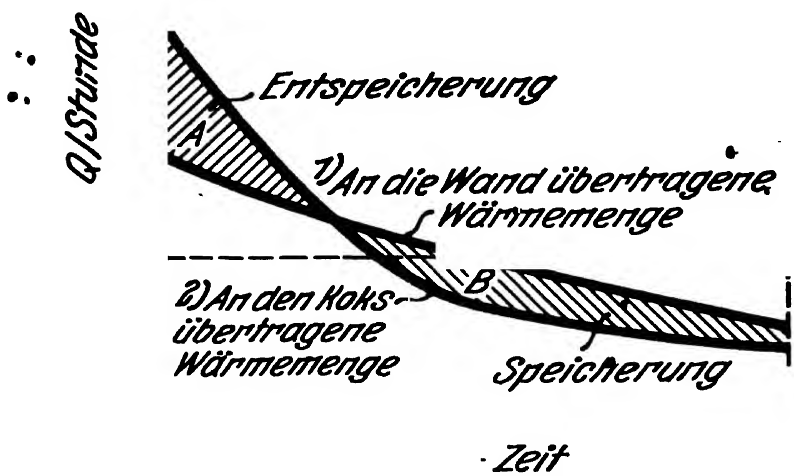

Fig. 1. Theoretical relationship between the heat flow through the wall of a coke oven and the coking period.

Ordinates = Quantity of heat per hour.
Abscissæ = Time.
Entspeicherung = Discharge of heat.
Speicherung = Storage of heat.
(1) An die Wand ubertragene Warmemenge = Quantity of heat transferred to the wall.
(2) An den Koks ubertragene Warmemenge = Quantity of heat transferred to the coke.

For comparison with the theoretical course of the heat flow shown in Fig. 1, measurements made in a coke oven battery with silica walls are shown in Fig. 2.[3]

The curve in Fig. 2 was obtained in the following manner:—

Thermo-elements were built into the walls of coke ovens in the positions shown in Fig. 3, and temperature readings were taken during the carbonisation of several charges. The heat flow through the wall could then be calculated from the readings by assuming a definite conductivity, λ, for the material of which the wall was composed. Since, moreover, the heat stored in, or released,

[3] Each point represents the mean of two readings. The points have been connected by arbitrarily chosen lines.

from the wall, can be calculated from the temperature fluctuations, it is also possible to calculate the amount of heat supplied to the coke.

The deviations from the curve in Fig. 1 are considerable. Several alternations of storage and emission of heat occur, due, as further investigation showed, to irregularity in the heating. The irregularities vary more or less erratically in the individual experiments, and are in some cases considerably greater than are shown in Fig. 2.

Fig. 2, moreover, does not represent a normal case, since during the coking period in question the heat supply became somewhat less towards the end of the period, and, consequently, several alternations of heat storage and heat emission occurred towards the end of the period, whereas if the heating had been uniform at the end of the period steady storage of heat would have occurred towards the end of the coking period, though to a diminishing extent, since the material of the wall can only attain a definite content of heat even if heating is carried out continuously over an infinitely long period.

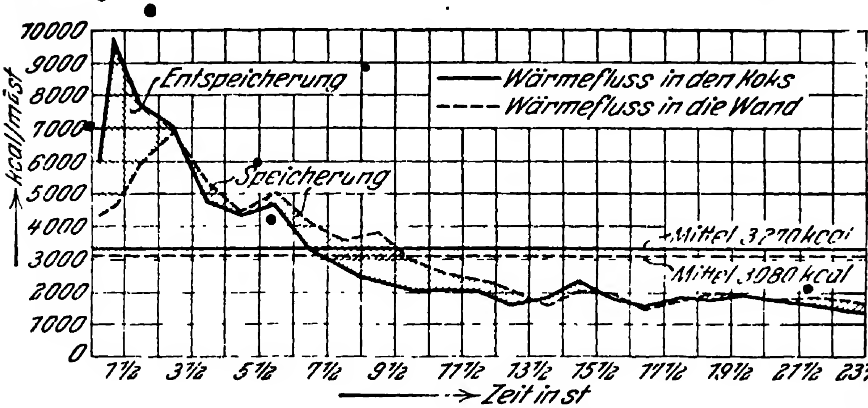

Fig. 2. Observed relationship between the heat flow through the wall of a battery of silica coke ovens, and the coking period.

Ordinates = Kg. cals. per sq. metre per hour.
Abscissæ = Time in hours.
Entspeicherung = Discharge of heat.
Speicherung = Storage of heat.
Warmefluss in den Koks = Heat flow into the coke.
Warmefluss in die Wand = Heat flow into the wall.
Mittel = Average.

The several alternations of heat storage and heat emission shown in Fig. 2 have no connection with the individual change-over periods. It is true that the latter also are characterised by alternate storage and emission of heat, but in calculating Curve 2, the effects of these have been eliminated by taking the average values of the individual measurements. It may be added that the fluctuations due to the half-hourly reversals do not extend into the coke, but are confined to the interior of the wall.

In Fig. 4, the upper curve shows the highest, and the lower curve the lowest temperature during one period between reversals in connection with the calculations from one set of measurements. The amount of heat stored up

due to the reversal amounted, during half an hour, to about 600 kilogramme calories per square metre in the case of a silica battery, and to about 450 kilogramme calories per square metre in experiments on a firebrick battery.

Fig. 2 also shows the averages of Curves 1 and 2, and indicates that during the coking period in question the total heat released was, approximately, 4,500 kilogramme calories, or 6 per cent., of the heat supplied to the coking chamber. It is remarkable that the value should have been so large, and

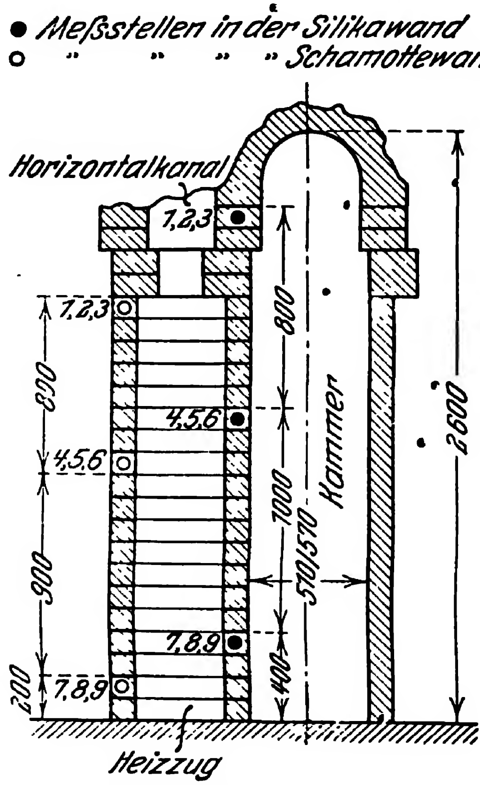

Fig. 3. Position of the thermo-couples in the heating wall.

Messtellen in der Silikawand = Measuring points in silica wall.
Messtellen in der Schamottewand = Measuring points in firebrick wall.
Horizontalkanal = Horizontal flue.
Kammer = Chamber.
Heizzug = Heating flue.

this shows that in tests on the heat consumption of coke ovens the measurements should always extend over several coking periods, as it is by no means certain that the temperatures of the walls of the battery at the end of the test correspond with the conditions at the commencement of the test.

Values for the amount of heat stored or released during a single coking period were found on occasion to approach 1,000,000 kilogramme calories per coking period for the whole coking chamber; thus, for example, it was found in one experiment that the heat storage was approximately 17,500

kilogramme calories per square metre during one coking period. The magnitude of this amount will be realised from the fact that during the same experiment the heating surface was supplied on the average with only 3,300 kilogramme calories per square metre per hour during the whole coking period.

If the average heat flow as shown in Fig. 2 be analysed with reference to the height above the oven floor of the individual thermo-couples (see Fig. 3), it is found that the heat flow was greatest below, whereas the highest portions of the wall, at the level of the horizontal flue, transmitted small amounts of heat only. It is not without interest that, on occasion, a return flow of heat may even occur through the upper part of the wall. Fig. 5 shows such a case, which, however, was only observed to so marked a degree on a single occasion, and must not, therefore, be taken as normal.

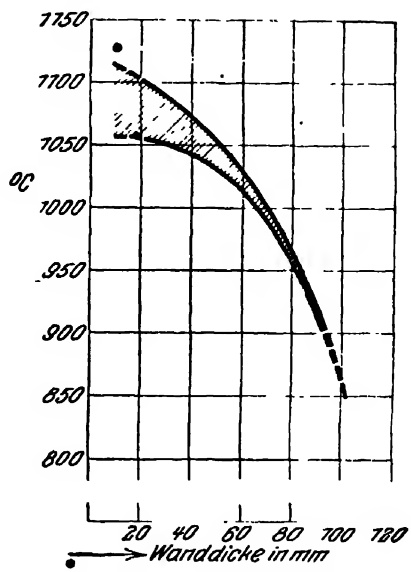

Fig. 4 The relation between heat storage during a gas flow cycle and the thickness of the oven wall

Ordinates = Degrees Centigrade.

Abscissæ = Wall thickness in mm.

In Fig 5, heat flow across five different types of surface can be distinguished:—

(a) Heat flow from the heating flue to the coke.
(b) Heat flow from the oven wall to the coke (heat release).
(c) Heat flow from the heating flue to the wall (heat storage).
(d) Heat flow from the coke to the wall (heat storage).
(e) Heat flow from the coke to the heating flue.

At this point, therefore, in contrast to the normal direction of heat flow, heat actually passed out from the coke through the oven wall and heated the gas in the horizontal flue.

Fig. 5 also shows the average surface temperature of the flue side of the wall (Curve 3), and the average temperature in the middle of the wall

thickness (Curve 4), in each case with respect to the height at which the thermo-couples were placed.

In Fig. 6 the heat flow with silica walls and firebrick walls is compared. The higher heat transmission of the silica battery corresponds with the higher heat conductivity of silica, and results in a coking period which is about 25 per cent. less.

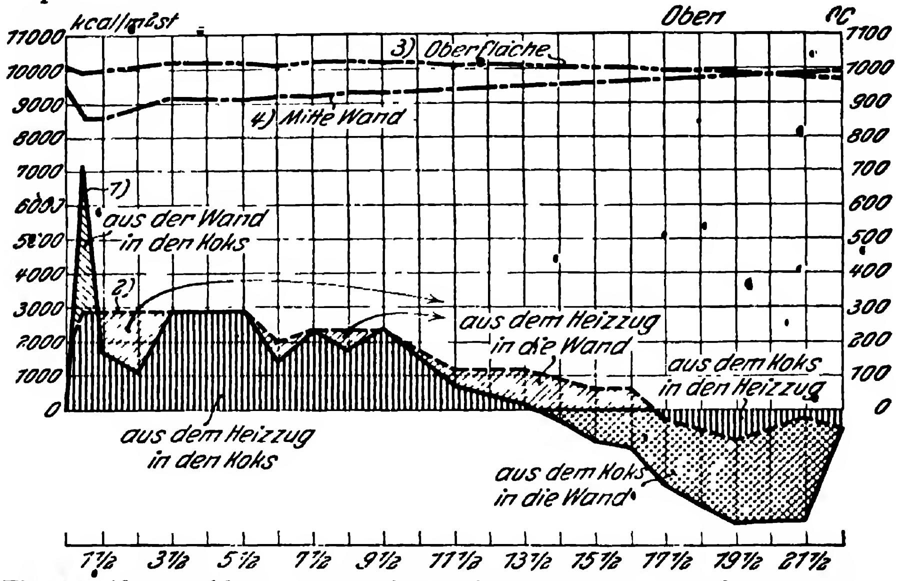

Fig. 5. Abnormal heat transmission at the uppermost point of measurement. (Firebrick coke ovens.)

Curve 1. Heat transferred to the coke.
Curve 2. Heat transferred from the heating flue to the wall.
Curve 3. Mean surface temperature of the wall.
Curve 4. Mean temperature of the wall.

Oben = Top.
kcal/m²st = kilogramme-calories per sq. metre per hour.
Oberfläche = surface.
Mitte Wand = Middle of wall.
aus der Wand in den Koks = From the wall to the coke.
aus dem Heizzug in die Wand = From the heating flue to the wall.
aus dem Koks in den Heizzug = From the coke to the heating flue.
aus dem Heizzug in den Koks = From the heating flue to the coke.
aus dem Koks in die Wand = From the coke to the wall.

(C) Conclusions.—Firstly, Figs. 3, 5 and 6 show how essential it is that the heat supply to the combustion chambers should be uniform, and, therefore, how necessary it is to secure that for each oven the product of the quantity of fuel gas and its calorific value shall remain constant. Fig. 7 represents the results obtained after correction for effects due to the temperature fluctuations caused by the reversals, and also for the progressive increase of wall temperature which occurs during a coking period. The curve shows the temperature variations of thermo-couple 8 (compare Fig. 3) and also the curve for the product (calorific values × quantity of fuel gas) over a comparatively short interval. A general similarity in the course of the two curves is noticeable. Similar results were frequently observed.

Secondly, emphasis must be laid on the necessity for a constant control of the temperature in all heating flues. This is now standard practice in all well-managed coke ovens. It is only in this way that a uniform heat supply can be achieved. During the experiments particular attention to temperature control was deliberately avoided.

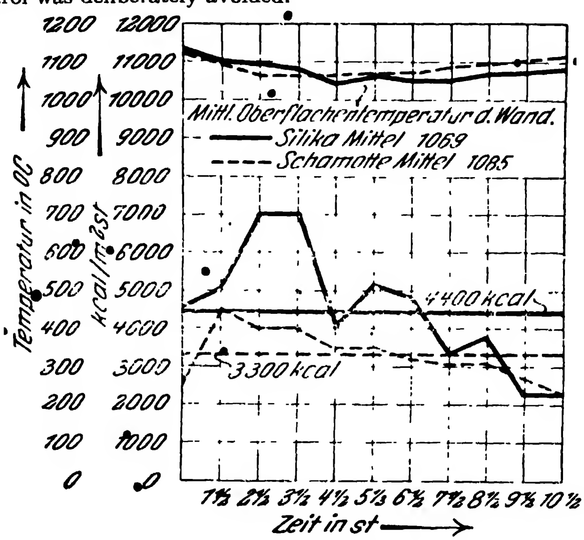

Fig. 6. Comparison between the heat flow through firebrick walls and silica brick walls during the early stages of coking.

kcal/m²st = kilogramme-calories per sq. metre per hour.

Mittl. Oberflachentemperatur d. Wand = Average surface temperature of wall.

Silika Mittel = Silica average.

Schamotte Mittel = Firebrick average.

Zeit in st. = Time in hours.

Thirdly, the question was investigated whether it was not possible to maintain the wall temperature in the heating flue constant during the whole coking period. Fig. 8 shows how very much the temperature in the wall may fall at the commencement of the coking period. By regulating the gas flow, the temperature could be maintained at an approximately constant value, and Fig. 9 illustrates the experiment in which temperatures were regulated in this sense. The result was a decrease of about 12·5 per cent. in the coking period, with the production of a coke of equally good quality.

Fourthly, the experiment showed how necessary it is always to extend measurements on the heat consumption of coke ovens over several coking periods, in order that the influences of any heat storage in or heat release from the wall may be spread over a long period.

(D) Effective Heat.[4]—The following summary analyses the total heat; that is, it divides the right-hand side of the heat balance into individual items:

[4] The considerations advanced in this section and in the following sections depend mainly on the investigations carried out by Dipl. Engineer Oestrich, on behalf of the Fuel Laboratory of the Verein deutscher Eisenhüttenleute.

TOTAL HEAT

- I. Effective heat.
  - 1. Expulsion of water.
    - (a) Evaporation.
    - (b) Superheat.
  - 2 Coking.
    - (a) Minimum heat of carbonisation.
      - (α) Sensible heat of the coke
      - (β) Sensible heat of the gas.
      - (γ) Heat of dissociation.
    - (b) Excess heat of carbonisation.
      - (α) Increase of the sensible heat of the coke.
      - (β) Increase of the sensible heat of the gas.
      - (γ) Additional heat of dissociation.
  - Superheating in the gases.
    - (a) Sensible heat.
    - (b) Heat of dissociation.
- II. Loss in flue gases.
- III. Radiation and conduction losses.

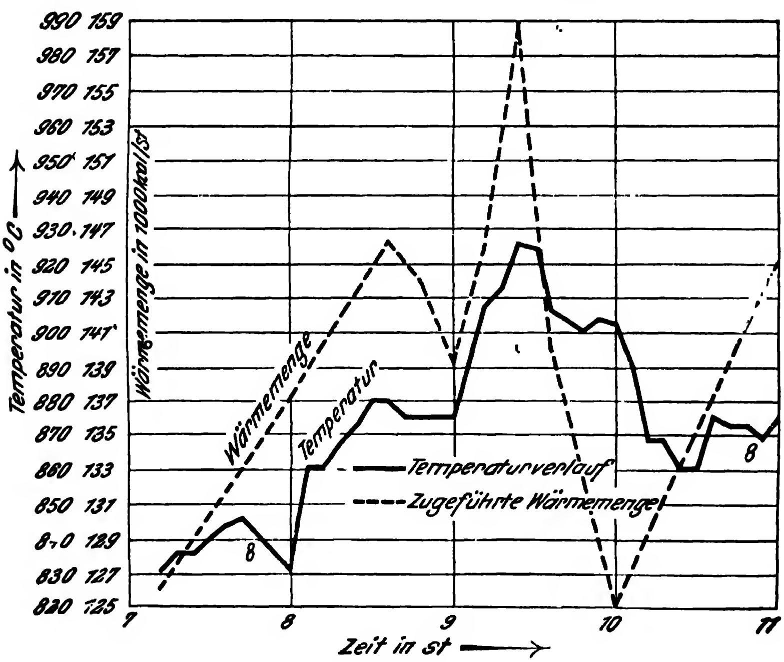

Fig. 7. The relationship between heat supply and heat flow.

Wärmemenge in 1000 kcal/st = Quantity of heat in 1000 kilogramme-calories per hour.

Zeit in st = Time in hours.

Wärmemenge = Quantity of heat.

Temperaturverlauf = Temperature variation.

Zugeführte Wärmemenge = Heat supplied.

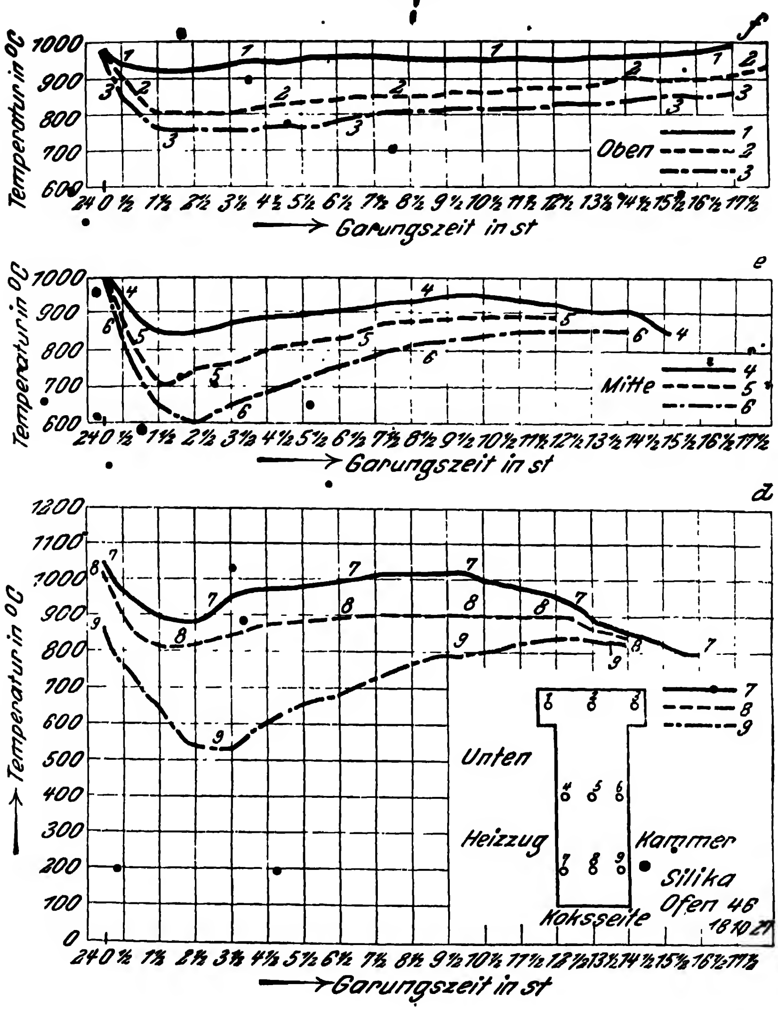

Fig 8. Fall of temperature at the commencement of the coking period with ordinary heating.

Garungszeit in st = Coking period in hours.

Oben = Above.

Mitte = Middle.

Unten = Below.

Heizzug = Heating flue.

Kammer = Chamber.

Koksseite = Coke side.

Silika Ofen = Silica oven.

The following explanations may be added regarding the terms here employed:

1. *Effective Heat.* (Compare Section A.)

The effective heat is influenced by both the design and condition of the ovens and their operation, and, finally, by the quality of coal treated. It is very difficult to distinguish the effect of these various factors, but the relationships between them are not different from those in any other furnace or in a steam boiler. In this case also, for example, a test of the behaviour of the oven, as regards, for instance, the fulfilment of the guarantees given in respect of its working, can only be carried out on the assumption of a definite standard of supervision which should be as high as possible, and of the use of a definitely specified coal. If, on the other hand, the question arises of determining by practical experiment the individual heat requirements of different kinds of coal, the experiments must be carried out in the same oven, in the same condition, and with equally good control of operating conditions.

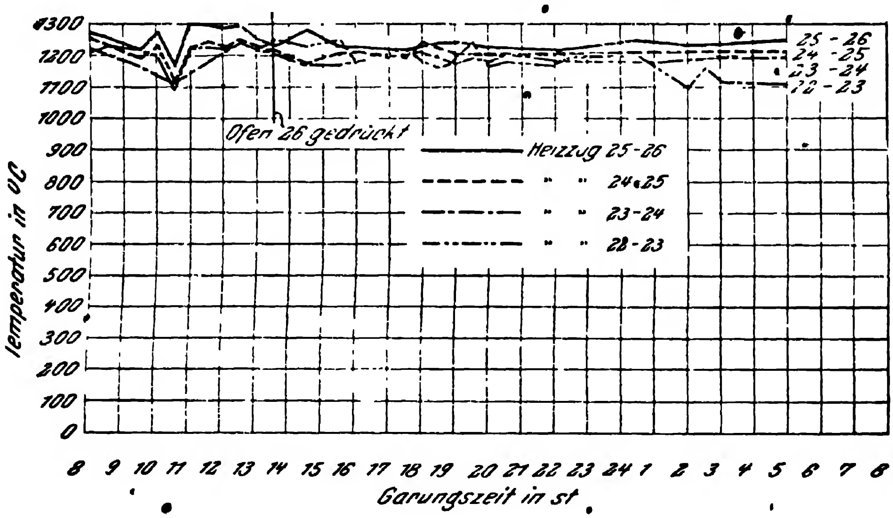

Fig. 9. Experiments with regulated temperatures, temperatures observed at the nostrils.

Ofen 26 gedrückt = Oven 26 discharged.
Heizzug = Heating flue.
Garungszeit in st = Coking period in hours.

The effective heat, that is, the heat required in practice for carrying out the coking process, may be divided into fractions representing the heat required for

1. Elimination of water,
2. Coking, and
3. Superheating the gas.

The heat consumed in coking the coal and in superheating the gas represents the effective heat required for the dry coal. This value is of importance for purposes of comparison and its determination will be discussed later.

1. *Elimination of water.* The first process occurring in a coke oven is the evaporation of water; the steam produced is generated at a temperature of about 100°C., corresponding with the pressure in the coking chamber, and

being confined laterally by the plastic layer, rises in the centre of the charge, at the same time becoming superheated. Above the charge the steam mixes with the hot gases rising on the other side of the plastic layer. The mixture is exposed to the influence of the wall temperature of the space from which it passes to the gas off-take. The extent to which the steam is superheated before it escapes from the charge is unknown, but some assumption as to the degree of superheat must be made before the heat required for the elimination of the water can be calculated. In absence of definite knowledge, a temperature of about 150°C. may be assumed, in which case 670 kilogramme calories would be required for the elimination of each kilogramme of water. The calculation to a dry coal basis of the effective heat expressed in terms of wet coal is then as follows:—

(a Kg. dry coal $\times y$ Kg. cals. per Kg. dry coal) + (b Kg. water $\times 670$) =
(($a + b$) Kg. wet coal $\times x$ Kg. cals per Kg. of wet coal).

(For further details, see Communication No. 106 of the Fuel Laboratory of the Verein deutscher Eisenhüttenleute, Dusseldorf.)

The proportion of the *total* heat required for each of these three items is found by multiplying y, 670 and x by the factor

$$\frac{\text{Total heat}}{\text{Effective heat}} = \frac{1}{E}$$

2 *The heat of carbonisation* may be sub-divided into:—

(*a*) Minimum heat of carbonisation,
(*b*) Excess heat of carbonisation.

The excess heat of carbonisation would be equal to zero if it were possible to bring the whole body of the coke simultaneously to the final coking temperature. As this is not possible, more heat must be employed, resulting in local superheating of the coke.

The excess quantity of heat required plays an important part in the heat balance only if markedly endothermic decompositions occur when coke is superheated. This may, in fact, occur; thus, for example, E. Terres and H Wolter[5] have shown by laboratory measurements in the case of coal from the Zollverein Colliery in Westphalia, that on heating coke from 1,000° to 1,050°C., an additional quantity of heat is absorbed amounting to no less than 80 kilogramme calories per kilogramme of dry coal. The heat absorbed during this reaction is recovered in the form of an increased calorific value of the coke and gas, whilst, on the other hand, it leads to a corresponding reduction in the temperature of the oven.

The effect of the increased time required due to over-coking on the radiation and conduction losses per ton of coke is small. If the coking period is increased by 10 per cent. through the inevitable over-coking, and if the radiation and conduction losses in the heat balance are 6 per cent., the increase of these through the increased coking period is $0{\cdot}1 \times 6 = 0{\cdot}6$ per cent. There is a tendency to over-estimate the magnitude of this effect and to assume that the greater part of the heat consumed in the heating flues during the over-coking period is lost, whereas, if the heating be properly carried out, this

[5] "Über die Verkokungswärme von Gas- und Kokskohlen," *Gas- und Wasserfach*, 70, (1927), Parts 1-4.

heat is actually stored up in the oven wall and is released later. The possibility realisable, for instance, in the case of narrow ovens, of having only a short over-coking period is linked up with a shorter coking period and a consequent increase of oven throughput per square metre of heating surface per hour. This increased throughput applies both to the quantity of coal or coke passed through the oven and also to the heat transmitted hourly by the heating flues and the wall; as regards the latter, this is so because, if the over-coking period is shorter, the temperature drop between the wall of the oven and the centre of the coke is smaller, and, therefore, for equal flue wall surface temperatures the temperature drop across the oven wall becomes larger, and, therefore, more heat flows through the wall. In narrow chambers the coking period is shortened, mainly due to the fact that a greater consumption of fuel gas is obtained per cubic metre of oven capacity, as the heating surface per cubic metre of oven space becomes larger

If the heat required for over-coking be deducted from the heat of carbonisation, or if the heat for over-coking is zero, as in the laboratory crucible coking test, the "minimum heat of carbonisation" is obtained. This represents the amount of heat necessary to raise the coke to the final temperature and the gas to its temperature of formation. It comprises the following items:—

(α) Sensible heat of the coke at the final coking temperature.
(β) Sensible heat of the gas at its temperature of formation, the assumption being made that it escapes at that temperature.
(γ) Heat of decomposition, comprising all processes which evolve or absorb heat and which occur during the conversion of dry coal at the charging temperature into coke and gas at the final temperature (see above under α and β), that is, inclusive of the latent heats of conversion from one state of aggregation into another.

3. *The superheating of the gas* which occurs in coke-oven operation is due to the fact that the gases are unable to escape at the temperature at which they are formed, but are heated during their ascent through the hot coke, the heat so absorbed is not included in the heat of carbonisation, as coking would occur even though the gases were not superheated. The quantity of heat necessary for superheating the gases must, therefore, be considered as a special item of the effective heat In this case also, decomposition processes may occur, but nothing is yet known as to their magnitude, and for the time being they must, therefore, be ignored. No calculation of the sensible heat of the superheated gas can be undertaken, since the quantity and composition of the gases which are evolved at the various temperatures are unknown. The final temperature of the gases when they escape from the coke body will approximate to the temperature of the latter. When the gases become mixed with the steam rising from the other side of the plastic layer their temperature is reduced again. (Compare references under heading 1.)

A few investigations have been published on the subject of the heat of decomposition of coal,[6] and it has been shown that the heat of decomposition varies

[6] E. Terres and A. Schaller, *Gas- und Wasserfach*, 65, (1922), p. 762.
J. Davis, *Fuel*, 4, (1925), p 286.
Burke and Parry, *Ind. & Eng. Chem.*, 19 (1927), p. 15.
E. Terres and H Wolter, *Gas- und Wasserfach*, 70, (1927), pp. 1-5, 30-35, 53-58 and 81-85.

with the nature of the coal within wide limits; thus, for example, Terres and Wolter found that the heats of decomposition of the Westphalian coals examined by them varied between +40 and — 120 kilogramme calories per kilogramme of coal, and, apparently, even wider variations occur. In any case, the values involved are of such a magnitude that they can certainly not be neglected in the heat balance. Even on the basis of the figures given by Terres and Wolter, minimum heats of carbonisation varying from 286 to 438 kilogramme calories per kilogramme of coal are found.

(E) CONCLUSIONS RELATIVE TO GUARANTEES WHICH CAN BE GIVEN BY THE COKE OVEN CONSTRUCTOR, AND RELATIVE TO COKE OVEN PRACTICE.—In the preceding section it was shown that the minimum heat of carbonisation varies within wide limits with the nature of the coal. Consequently, it is not possible, without a knowledge of the heat of carbonisation, to demand of the oven constructor a guarantee covering the heat requirements of the ovens per kilogramme of coal, or to use a standard figure for the heat requirements per kilogramme of coke, in assessing the performance or operation of ovens working on different classes of coal. Moreover, it is equally unjustifiable, without a knowledge of the heat of carbonisation, to demand a guarantee as to output or coking period, or to use these figures as a basis for comparing ovens handling coals of different types. These statements represent a point of view different from the existing attitude.

It is true that a determination of the minimum heat of carbonisation of various types of coal is possible in the laboratory, but the investigation is very difficult quite apart from the fact that an experimental apparatus suitable for use in works has not yet been devised. However, it is not implied that even if such tests were carried out, the results would with certainty correspond with the minimum heat of carbonisation in actual operation of a coke oven, since, for instance, in the coke oven the course of the coking process differs from that in the laboratory in that it extends over several hours instead of being confined to a mere matter of minutes. However, even if the minimum heat of carbonisation at a definite temperature could be determined with sufficient exactitude, it would still remain to be ascertained whether the minimum temperature corresponding with this heat of carbonisation would actually be attained in all parts of the coke mass. It has, for example, been found that in consequence of the varying degree of carbonisation in the same oven, and with the same coal, differences in the heat consumption occur, amounting to 150 kilogramme calories per kilogramme of coal.[7]

In view of these difficulties it is not desirable to assess the performance of ovens in terms of the heat supplied by the combustion of the fuel gas and the minimum heat of carbonisation, namely, in the form

$$\frac{\text{Minimum heat of carbonisation.}}{\text{Heat from combustion of the fuel gas}}$$

There is, however, another possibility; the factor

$$\frac{\text{Effective heat.}}{\text{Heat from combustion of the fuel gas}}$$

[7] Unpublished experiments by the Boiler Control Association of the Collieries of the Dortmund Oberbergamtsbezirk, Essen.

forms an excellent basis for assessing the performance of ovens and, therefore, for the working out of guarantees.

The heat supplied by the fuel gas can be measured and the effective heat can be determined from the equation derived from heat balance in section A.

Effective heat = (total heat supplied)—(loss in the flue gases)—(radiation and conduction losses).

(*a*) The *total heat supplied* may, as a first approximation, be taken as equal to the heat arising from the combustion of the fuel gas, but the heat supplied in the form of the sensible heat of the air and of the coal may naturally be included for more accurate calculations.

A further method of determining the *effective heat*, serving as a check on the above calculation, can be deduced from the following considerations, to which the attention of the author was drawn by G Neumann. From Heat Balances I. and II. of Section A, Heat Balance III. can be obtained by subtraction.

HEAT BALANCE III.

	Kilogramme calories		Kilogramme calories
I. Calorific value of the coal charge		I Calorific value of the coke	
II. Effective heat		II. Calorific value of the surplus gas	
		III. Sensible heat of the coke	
		IV. Sensible heat of the surplus gas	
		V. Latent and sensible heat of the steam	
Total		Total ...	

The effective heat is, therefore, equal to the difference between the heat energy of the coal charge and that of the net yield of carbonisation products.

There is thus obtained the possibility of calculating the effective heat, though naturally all the errors inherent in a method based on differences are involved, especially in view of the uncertainty with which the correct mean values can be determined.

(*b*) The heat lost in the flue gases can be calculated from their volume and temperature. The volume is preferably obtained by direct measurement but if it is impossible or undesirable to measure the gases, their volume must be calculated in the usual manner.

The radiation and conduction losses can be determined with sufficient exactitude if the temperatures of the outer walls of the battery of ovens are determined. The radiation and conduction losses are best grouped into the losses from the upper oven and those from the lower oven; for the upper oven they are calculat d from the equation:—

$$Q = \beta F (t_1 - t_2)$$

The value β includes the influence of convection, α, and radiation α_s, and is equal to:—

$$\alpha + \alpha_s$$ [8]

Radiation losses are best investigated in dry, calm weather, and with a clouded sky, as the radiation factor is known with greatest accuracy for these conditions. The heat losses are not dependent on the weather to a very great extent, for the reason that the main barrier against the passage of heat is the masonry itself, and the heat transmission factor k, in the equation:—

$$Q \quad k.\ F.\ (t_1 - t)$$

where

$$\frac{1}{\frac{1}{\beta} + \frac{\lambda}{\delta} + \frac{1}{\beta_1}}$$

depends mainly on the heat resistivity of the masonry and on the heat resistivity, $\frac{1}{\beta_1}$, of the inside of the oven. The heat losses are, therefore, greater only to the order of 10 per cent. in presence of rain or wind.

The radiation loss from the lower oven is determined from measurements of the surface temperature of the walls of the regenerators by way of the inspection passages. In the calculation, however, account must be taken of the fact that at these points the temperature of the opposite wall is higher than that of the surroundings when radiation occurs into the open. The heat loss per square metre per hour for various wall temperatures can be easily determined with a heat-flow meter.

As the efficiency of the oven equals $\frac{\text{Effective heat}}{\text{Heat supplied}}$ it can be determined during the guarantee test. It is, therefore, a quantity as to which a guarantee can be demanded from the oven constructor. This is, in fact, the only guarantee covering the efficiency of the heating which he can give. He can do nothing beyond applying heat to the oven walls and passing as great a quantity as possible of the heat through the walls to the coke.

In coke ovens the chief concern is not merely the heat consumption, but throughput is equally of importance. It is, therefore, usual to specify a definite coking period for the ovens. The coking period is, however, not merely dependent on the design of the ovens, but also, just as is the heat consumption per kilogramme of coal, on the nature of the coal treated. Time is always required for heat transfer. As even dry coals differ considerably as regards their heat of carbonisation, it cannot be expected that all coals should be coked in the same period. Even though a correction formula for converting the results to a dry coal basis can be applied when the moisture content varies, such a correction is impossible for coals of varying heats of carbonisation, until such time as these values become known.

It may, however, be said that the coking periods are the shorter the more heat is passed into the chamber per hour, that is, the more fuel gas is burned per hour with a definite degree of efficiency. Types of coal which require a particularly slow heating rate for the production of coke of good quality

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[8] Values for α and α_s and examples of the calculations are contained in Communication No. 51 of the Fuel Laboratory of the Verein deutscher Eisenhüttenleute (Düsseldorf) 1923, p. 17.

therefore require a correspondingly longer coking period. In the case of all other types of coal, the amount of heat transferred per hour to the coking chamber is limited by the highest temperature which the bricks will stand.

It is, therefore, important that a definite quantity of fuel gas should be burned per hour. It may, therefore, be demanded that the oven constructor should guarantee that a definite consumption of fuel gas should be realisable and that at the same time a predetermined wall temperature should not be exceeded. However, with a predetermined temperature in the combustion chambers or a predetermined consumption of fuel gas, the coking period of a particular coal with a given moisture content may vary because the heat consumed in over-coking varies. If the fact be ignored that bad control of the ovens may increase the heat consumed in over-coking to an unnecessarily great extent, the art of the oven constructor may be said to consist in heating the oven wall so uniformly, and in choosing the dimensions of the chambers and the walls in such a manner, that a minimum amount of heat is used for over-coking. This heat is the smaller the more uniform are the temperatures within the coke mass at the end of the coking period.

The degree of uniformity of the temperatures within the coke mass is capable of being measured during the guarantee test, and it is, therefore, possible to include in the guarantees a statement to the effect, for example, that when at a definite point in the median plane a temperature of 1,000°C. is attained, a specified minimum temperature shall have been reached at other definite points in the median plane.

The following guarantees may, therefore, be demanded:—

1. Good oven efficiency.
2. High consumption of fuel gas per hour per cubic metre of chamber volume with a definite wall temperature.
3. Very small temperature differences in the median plane of the coke mass.

A governing factor will be the heating surface per cubic metre of effective chamber capacity.

For the guarantee tests a number of definite conditions must be fixed. Thus, for example, the duration of the test must be decided. It must extend over at least three coking periods in order to eliminate the influence of heat storage in the bricks. The brickwork of an oven weighs approximately 50 tons and a change in temperature of 50°C throughout its mass involves an error in one coking period of about 770 kilogramme calories per kilogramme of wet coal charged.

Moreover, it must, for example, be decided whether the flue gas temperature is to be determined with a suction pyrometer, whether the temperatures in the flues shall be measured with a thermo-couple, at what points the temperatures are to be measured (whether at the chimney end or in the horizontal flues or in the descending vertical heating flues—this for the avoidance of errors caused by flame radiation on to thermo-couples), and how and in which, and in how many individual ovens the temperatures in the coke mass are to be determined. An agreed method for analysing the collected samples of the flue gas must be decided upon, the method of determining the radiation and conduction losses must be settled and so forth.

For strict accuracy, items allowing for the influence of leakage through the oven walls ought to be included in the heat balance of the coke oven. In a new battery of ovens in which a guarantee test is perhaps to be made, such leakages can be ignored if the pressure between the chamber and the heating flues is small. In the continuous operation of older batteries leakages will, however, easily occur, so that in such cases the heat balance determined regardless of such leakages will not be correct.

The influence of leakages will now be considered more closely. Unsound heating walls have the greatest effect. If coke oven gas passes from the chambers into the heating flues and burns there, an extraneous heat supply which is not entered in the heat balance results. When the effective heat is determined by difference, this error results in a reduction of the apparent effective heat, and the calculated efficiency becomes lower, such leakages therefore give rise to an apparent reduction in the efficiency of the oven. If the escaping coke oven gas burns incompletely or too late, the apparent efficiency becomes even worse in consequence of the increased loss in the flue gas.

If unburnt fuel gas enters the coking chamber through leakage, the calculated efficiency becomes higher. However, such losses through leakage are comparatively rare. In batteries using gas of low calorific value, cracks in the oven floors may lead under the prevailing conditions to the passage of fuel gas from the regenerator chambers into the coking chambers. If appreciable quantities of unburnt gas pass in this manner the consumption of fuel gas per hour for a given wall temperature must increase, and, of course, the hourly gas consumption reflects one aspect of efficiency. (In the first-mentioned case, namely, passage of coke oven gas into the heating chamber, the hourly consumption of fuel gas would decrease.) In general, the consumption of fuel gas should be uniform. Leakages in the horizontal flues are usually indicated by visible flames at the point of exit of the coke oven gas.

The continuous record of the efficiency of firing and of the consumption of fuel gas per square metre of heating area or per cubic metre of chamber capacity, thus gives an indication as to the soundness of the walls. These two figures are, of course, also dependent on the efficiency of the plant control and especially on the uniformity of the heating. If the moisture content of the coal alters or, more particularly, if the coal is changed, involving an alteration in the heat required for the decomposition the efficiency must also change.

In all cases, the coking period, the firing efficiency, and the specific fuel gas consumption, in terms of the heating surface, the chamber capacity and the weight of coke produced are data which must be included in all reports dealing with coke oven tests.

(F) SUMMARY.—The importance of the coke oven wall as a heating surface is very great. The heat flow through the wall indicates the not inconsiderable magnitude of the storage and discharge of heat during the periods between reversals and during the coking periods. Heat storage between reversals amounts to something in the neighbourhood of 500 kilogramme calories per period per square metre of heating surface. Heat storage during a single coking period was found by experiments to amount to anything up to about 17,500 kilogramme calories per square metre of heating surface. The total

heat supply during this storage amounted to about 3,300 kilogramme calories per hour per square metre of heating surface. The quantities involved are therefore large. It was found also that the amount of heat stored up during one coking period was by no means always equal to the amount of heat released during the same period; for example, in one of the tests about 150 per cent. of the amount of heat which was released at the commencement of the coking period was subsequently stored up. The flow of heat in the wall itself was very irregular, and this was also true of the flow of heat into the coke. All this points to the necessity of strict temperature control, though this was deliberately not exercised during the investigations. On the contrary, it was left to the staff to adjust the battery in such a manner as appeared to them desirable

The formulation of a heat balance necessitates a critical sub-division of the heat passing through the oven wall as regards the amounts passing to various destinations. The actual heat requirement, that is, the "minimum heat of carbonisation," is very largely dependent on the chemical reactions taking place during the coking process This fact leads to the further conclusion that it is impossible to assess the efficiency of a coke oven in terms of the heat requirements per kilogramme of coal charged or per kilogramme of coke produced, unless the endothermic or exothermic heat of decomposition of the coal under treatment is known. Also, the length of the coking period depends on the magnitude of the heat of decomposition.

With the help of modern measuring devices the effective heat of coking, which is approximately equal to the quantity of heat passing through the oven wall, can be calculated from the heat balance. If the effective heat be divided by the total heat supplied, the efficiency of the oven is obtained, and its value is to be considered an important index of the proper working of the oven and its control. Furthermore, the consumption of fuel gas per square metre of heating surface is indicated as providing a useful criterion. The figure expressing the consumption of fuel gas per cubic metre of oven capacity may also be of importance for comparative purposes. Finally, uniformity of coking throughout the contents of the oven is of importance, and can be studied by temperature measurements in the coke mass.

DER OBERE UND UNTERE HEIZWERT ALS GRUNDLAGE FÜR GARANTIEVERSUCHE

(THE USE OF GROSS AND NET CALORIFIC VALUES FOR THE PURPOSE OF GUARANTEE TESTS)

VEREINIGUNG DER DEUTSCHEN DAMPFKESSEL- UND APPARATE-INDUSTRIE, DÜSSELDORF, UND ALLGEMEINER VERBAND DER DEUTSCHEN DAMPFKESSEL-ÜBERWACHUNGS-VEREINE, MÜNCHEN

N. F. NISSEN

Paper No. G3

CONTENTS

Vorbemerkung des Deutschen Nationalen Komitees der Welkraftkonferenz

Das wissenschaftliche Für und Wider in der Frage der Verwendung des oberen und unteren Heizwertes darf im Kreise der Sachverständigen der Weltkraftkonferenz als bekannt vorausgesetzt werden. In Deutschland wurde im Jahre 1925 eine versuchsweise Regelung dahin getroffen, dass nach den "Regeln für Abnahmeversuche an Dampfanlagen" während einer zweijährigen Übergangszeit beide Heizwerte gleichzeitig Verwendung finden sollten. Vor endgültiger Festlegung entweder auf den oberen oder auf den unteren Heizwert würden die deutschen Sachverständigen eine internationale Aussprache in dieser Frage begrüssen. Der folgende Beitrag, der aus der Praxis der deutschen Dampfkessel- und Apparateindustrie hervorgegangen ist und die einhellige Billigung dieser Industrie hat, möge aufgefasst werden als ein Beitrag zu dieser Aussprache. Es ist aus dem technischen Schrifttum der Welt bekannt, dass auch in andern Ländern die Meinungen der Sachverständigen über diese Frage noch geteilt sind; es darf die Hoffnung ausgesprochen werden, dass eine internationale Aussprache den Weg zu einer allgemein anerkannten Regelung weisen möge.

Die Bewertung eines Brennstoffes ist in den einzelnen Ländern heute noch sehr verschieden. Nicht nur die Massbezeichnungen weichen voneinander ab, sondern auch über die Bewertung selbst herrschen noch verschiedene Meinungen und Gepflogenheiten.

In der Hauptsache liegt die Verschiedenheit der Ansichten in der Frage, ob man diejenige Warmemenge zu Grunde legen soll, die eine Gewichtseinheit eines Brennstoffes erzeugt, wenn alle beteiligten Stoffe vor und nach der Verbrennung 0°C haben, oder ob der Wärmeinhalt des in den Verbrennungsprodukten enthaltenen Wasserdampfes als nicht gewinnbar von dem ersteren Werte in Abzug gebracht werden soll. Es ist die Frage, ob der sogenannte obere oder untere Heizwert als Wertmasstab eines Brennstoffes geeigneter ist.

Dem ersteren gebührt der Vorzug der einfachen und klaren Definition; die Definition des zweiten erfordert die Vorstellung, dass sich die trockenen Gase allein zwar bis auf 0°C abkühlen können, dass aber der Wasserdampf sich nur bis zum Taupunkt abkühlen kann und mit seinem Wärmeinhalt, den er in diesem Punkt besitzt, aus der Rechnung verschwindet.

Weiterhin ist der Wärmeinhalt der Dampfmengeneinheit nicht bei allen Feuchtigkeitsgehalten gleich. Die jeweilige Errechnung ist zu umständlich, sodass Vereinbarungen notwendig werden, welche Wärmemenge je Gewichtseinheit Wasser von den Verbrennungsprodukten in Abzug gebracht werden soll.

In zahlreichen Ländern sind Bestrebungen im Gange, aus obigen Gründen den oberen Heizwert zu bevorzugen und ausschliesslich zu verwenden. Auch Deutschland führte im Jahre 1925 in seinen "Regeln für Abnahmeversuche an Dampfanlagen" anstelle des bis dahin ausschliesslich benutzten unteren Heizwertes den oberen ein. Während einer zweijährigen Übergangszeit sollten beide Heizwerte gleichzeitig Verwendung finden.

Die zweijährige Übergangszeit in Deutschland ist nunmehr abgelaufen, und man kann jetzt überblicken, dass sich die Einführung des oberen Heizwertes in der Praxis *nicht* hat verwirklichen lassen. Ein neuer offizieller Beschluss ist jedoch zurzeit noch nicht gefasst worden.

Alle beteiligten Kreise, die Hersteller von Feuerungen und Dampfkesseln, sowie die Betreiber und die bei Abnahmeversuchen als Sachverständige tätigen Dampfkessel-Überwachungsvereine sind zu der Erkenntnis gekommen, das nur der untere Heizwert für die praktische und einfache Bewertung einer Anlage in Frage kommt.

Zahlreiche Institute haben die Ausrechnung der Versuchsergebnisse nach dem oberen Heizwert ganz eingestellt. Garantien werden nur auf Grund des unteren Heizwertes gegeben und gefordert.

Es hat sich in Deutschland bei den verschiedenartigsten Brennstoffen, von dem magersten Koksgrus bis zur Rohbraunkohle mit über 50% Wassergehalt, das Bedürfnis nach einem Vergleichsmasstab herausgestellt, der die Qualität einer Anlage ohne wesentliche Beeinflussung durch den zufälligen Wassergehalt des verfeuerten Brennstoffes festzulegen gestattet.

So ist z.B. nicht einzusehen, dass einer Braunkohlenfeuerung, die mit dem gleichen Rückstandsverlust, dem gleichen Luftüberschuss und dem gleichen Verlust an unverbrannten Gasen betrieben wird wie eine Steinkohlenfeuerung, ein ganz wesentlich niedrigerer Wirkungsgrad zugeschrieben werden soll als der Steinkohlenfeuerung. Solche unerwünschten Ergebnisse erhält man aber, wenn man den Wirkungsgrad auf den oberen Heizwert aufbaut. In den Garantien ist der Wirkungsgrad ein wichtiger Masstab der Qualität einer Anlage.

Bei der Zugrundelegung des oberen Heizwertes wird aber in erhöhtem Masse der Einfluss des Wasser- und Wasserstoffgehaltes des Brennstoffes mit den Eigenschaften der Anlage verquickt.

Die auf die beiden Heizwerte bezogenen Wirkungsgrade haben eine gewisse Ähnlichkeit mit dem thermischen und dem thermodynamischen Wirkungsgrad der Wärmekraftmaschinen.

Ersterer gibt das Verhältnis der in mechanische Arbeit verwandelten Wärme zu der gesamten zugführten Wärme an, während der zweite die ausgenutzte Wärme in Teilen der überhaupt ausnutzbaren angibt. Nur der letztere hat eine Bedeutung für die Bewertung einer Maschine. Ähnlich so lässt der Wirkungsgrad, der auf den unteren Heizwert Bezug hat, den nicht ausnutzbaren Teil der Brennstoffwärme ausser Acht. Während nun die Werte der thermisch und thermodynamischen Wirkungsgrade weit auseinander liegen, also eine Verwechslung kaum möglich ist, verursacht das Nebeneinander vom oberen und unteren Heizwert und der auf sie bezogenen Wirkungsgrade leicht Irrtümer.

Schon allein die nähere Bezeichnung durch die Eigenschaftswörter (oberer und unterer) ist nachteilig, da dieselbe erfahrungsgemäss häufig fortgelassen wird. Es ist in Deutschland vorgeschlagen worden, anstelle des oberen Heizwertes: Verbrennungswärme (heat of combustion) zu setzen und statt des unteren Heizwertes einfach: Heizwert (heating value).

Zurzeit sind in England, den Vereinigten Staaten und in Frankreich folgende Bezeichnungen üblich:

Land	Massbezeichnung	Bezeichnung für den oberen Heizwert	Bezeichnung für den unteren Heizwert
England	B.Th.U. pr. lb.	Gross calorific value	Net calorific value
Ver.Staaten	B.t.u. pr. lb	Total oder gross calorific oder heating value	Net calorific oder heating value
Frankreich	cal pr. kg	pouvoir oder puissance calorifique	pouvoir oder puissance calorifique utile

Aber nicht nur für die Bewertung der Feuerungen und Kessel ist der (untere) Heizwert ausschlaggebend, sondern auch für die Brennstoffe; denn es hat offenbar nur einen Sinn, den Brennstoff nach dem Wert zu kaufen, den er für Heizzwecke hat, nämlich nach seinem Heizwert. Aus diesem Grunde wird auch im Kohlenhandel in Deutschland von allen Beteiligten (Erzeuger und Verbraucher) nur noch mit dem (unteren) Heizwert gerechnet.

Die angeführten *praktischen Vorzüge* des Heizwertes wiegen die erwähnten *theoretischen Nachteile* bei weitem auf. Es sei hier nur noch an zwei Beispielen gezeigt, welche entstellenden Ergebnisse durch Verwendung der Verbrennungswärme (des oberen Heizwertes) entstehen können:

Eine rheinische Rohbraunkohle mit einer

Verbrennungswärme von 2 459 kcal/kg
und einem Heizwert „ 2 002 „

mit geringem Gehalt an harmloser Asche werde in einer Anlage mit 76% Wirkungsgrad, bezogen auf den (unteren) Heizwert, verfeuert.

In einer anderen Feuerung werde ein Gemisch von Kokslösche und Staubkohle

mit einer Verbrennungswärme von 4 692 kcal/kg
und einem Heizwert „ 4 491 „

verfeuert.

Infolge des hohen Aschengehaltes seien die Verluste durch Unverbranntes in den Rückständen und die Abgasverluste infolge hohen Luftüberschusses hoch und der Wirkungsgrad, bezogen auf den (unteren) Heizwert, betrage nur 65%.

Bezieht man nun beide Wirkungsgrade auf die Verbrennungswärme (oberer Heizwert), so ergibt sich im ersteren Falle 62,0%, im

zweiten 62,3%; d.h. die schlechte Verbrennung wird noch etwas höher bewertet als die gute.

Im vorigen Beispiel werden Unterschiede in den Heizwerten hauptsächlich durch den verschieden grossen Wassergehalt bedingt. Aber auch bei gleichem Wassergehalt können irreführende Ergebnisse entstehen. Auf einem Wanderrost werde

einmal Koks von 10,7% Wassergehalt

mit einer Verbrennungswärme von 6 460 kcal/kg
und einem Heizwert „ 6 374 „

und

einmal Braunkohlenbriketts mit dem gleichen Wassergehalt

mit einer Verbrennungswärme von 5 222 kcal/kg
und einem Heizwert „ 4 924 „

verfeuert.

Der erstere Brennstoff habe wieder mit Rücksicht auf die erschwerte Verfeuerung mit einem etwas geringeren Wirkungsgrad abgeschnitten als der zweite. Beim ersten sei 79%, beim zweiten dagegen 81% Wirkungsgrad erzielt worden.

Bezogen auf die Verbrennungswärme (oberer Heizwert) ergibt sich dagegen für den Koks ein Wirkungsgrad von 78% und für die Briketts ein solcher von 76,5%; also umgekehrt wie es sein müsste. In diesem Falle ist die Abweichung durch verschieden grossen Wasserstoffgehalt der Brennstoffe bedingt.

Für Garantieversuche hat die Rechnung mit der Verbrennungswärme (dem oberen Heizwert) noch den grossen Nachteil, dass sich der mit ihm errechnete Wirkungsgrad ändert, wenn der Wassergehalt der Versuchskohle von dem vorausgesetzten Wassergehalt abweicht. Zwar tritt auch bei Bezug auf den (unteren) Heizwert mit zunehmendem Wassergehalt eine Abnahme des Wirkungsgrades ein. Diese Abnahme bewegt sich aber innerhalb des in Frage kommenden Bereiches in solchen Grenzen, dass bisher von den Feuerungs- und Dampfkesselherstellern keine besondere Umrechnung des Ergebnisses auf den zugrundegelegten Wassergehalt verlangt worden ist.

Bei Bezugnahme auf die Verbrennungswärme würde aber eine solche Umrechnung nicht zu umgehen sein.

Die Veränderung des Wirkungsgrades mit zunehmendem Wassergehalt ist in den beigefügten Abbildungen dargestellt.

Für sämtliche Abbildungen ist eine aschefreie Kohle zu Grunde gelegt, deren wasserfreie Substanz

einen (unteren) Heizwert von 7848 kcal/kg.

und eine Verbrennungs-

wärme (oberen Heizwert) ,, 8094 ,,

besitzt.

Ferner liegt die Annahme zu Grunde,

dass die Abgastemperatur beim Wassergehalt Null 260°C betrage,

und

dass die Heizfläche die überall gleiche Temperatur von 160°C besitze.

Weiterhin ist noch vorausgesetzt, dass die Heizfläche und die Dampfleistung des Kessels für alle Wassergehalte unverändert sei Die Verluste durch Unverbranntes in den Rückständen und Gasen, sowie die Strahlungsverluste sind ausser Acht gelassen, da lediglich der Einfluss des Wassergehaltes dargetan werden soll.

Zwei verschiedene Fälle sind in den Schaulinien untersucht worden. Im ersten Falle ist vorausgesetzt worden, dass der untersuchte Kessel zwar bei allen Wassergehalten dieselbe Heizfläche besitze, aber entsprechend der mit zunehmendem Wassergehalt zunehmenden Gasmenge mit grösseren Gasquerschnitten versehen sei. Das heisst also, der Kessel soll für jeden Wassergehalt so konstruiert sein, dass die Gasgeschwindigkeit, der Zugverlust und die Wärmeübergangszahl bei allen Wassergehalten gleichbleibend ist.

Im zweiten Falle ist ein Kessel mit unveränderten Abmessungen vorausgesetzt worden. Dieser Fall hat besonders für Abnahmeversuche Bedeutung.

Abbildung 1 zeigt die theoretische Verbrennungstemperatur, die angenommene Gastemperatur am Eintritt in die Berührungsheizfläche und die unter den beiden obigen Voraussetzungen ermittelten Abgastemperaturen.

Die Linie D in Abbildung 2 zeigt, welche zusätzliche Beeinflussung des Wirkungsgrades durch den Wassergehalt bei Zugrundelegung der Verbrennungswärme eintritt. Die Ordinaten geben an, um wieviel % sich der Wirkungsgrad zusätzlich verringert, wenn der Wassergehalt um 1% steigt.

Ist z.B. der Wirkungsgradgarantie ein Wassergehalt von 40% zugrunde gelegt und enthält die Versuchskohle 50% Wasser, so entsteht lediglich durch Verwendung der Verbrennungswärme (oberer Heizwert) eine Wirkungsgradabnahme von $10 \times 0{,}25 = 2{,}5$%, selbst venn der auf den unteren Heizwert bezogene Wirkungsgrad konstant bliebe.

Abbildung 4 zeigt die Wirkungsgrade bezogen auf den oberen und unteren Heizwert bei gleichbleibendem Kessel.

Die Linien H_1 und G_1 geben die absolute Änderung der Wirkungsgrade in Wirkungsgradeinheiten an, wenn sich der Wassergehalt um 1% ändert. Die Linien H_2 und G_2 stellen diese Änderung in % des

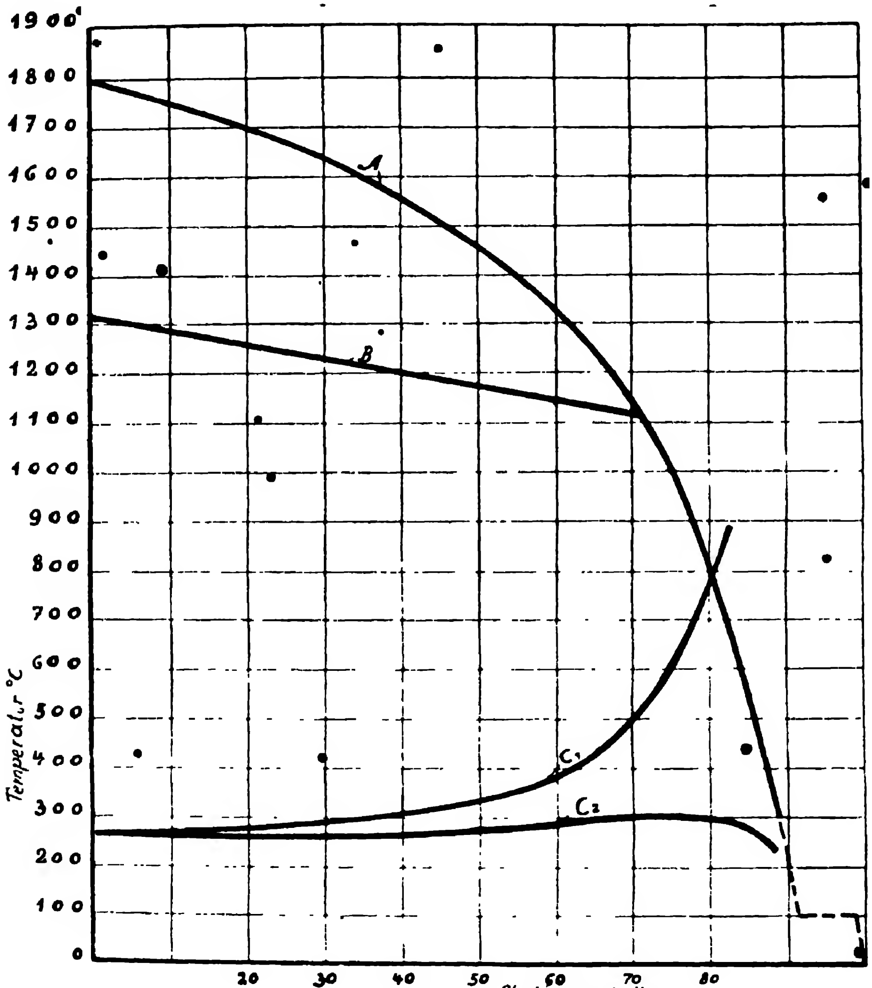

Abb. 1.

A Theoretische Verbrennungstemperatur.
B Gastemperatur am Eintritt in die Berührungsheizfläche.
C_1 Abgastemperatur bei gleichbleibender Wärmedurchgangszahl für alle Wassergehalte.
C_2 Abgastemperatur bei gleichbleibendem Kessel.

jeweiligen Wirkungsgrades dar. Man sieht daraus deutlich, dass der Wirkungsgrad, der auf den (unteren) Heizwert aufgebaut ist, wesentlich weniger vom Wassergehalt abhängig ist. Diese

Eigenschaft ist gerade beim Abnahmeversuch sehr wichtig. Es ist nicht möglich, beim Versuch stets Kohle vorzulegen, die genau den in der Garantie angegebenen Wassergehalt hat.

Ist z.B. für eine Anlage ein Wirkungsgrad von 73%, bezogen auf die Verbrennungswärme garantiert, und der beim Versuch benutzte

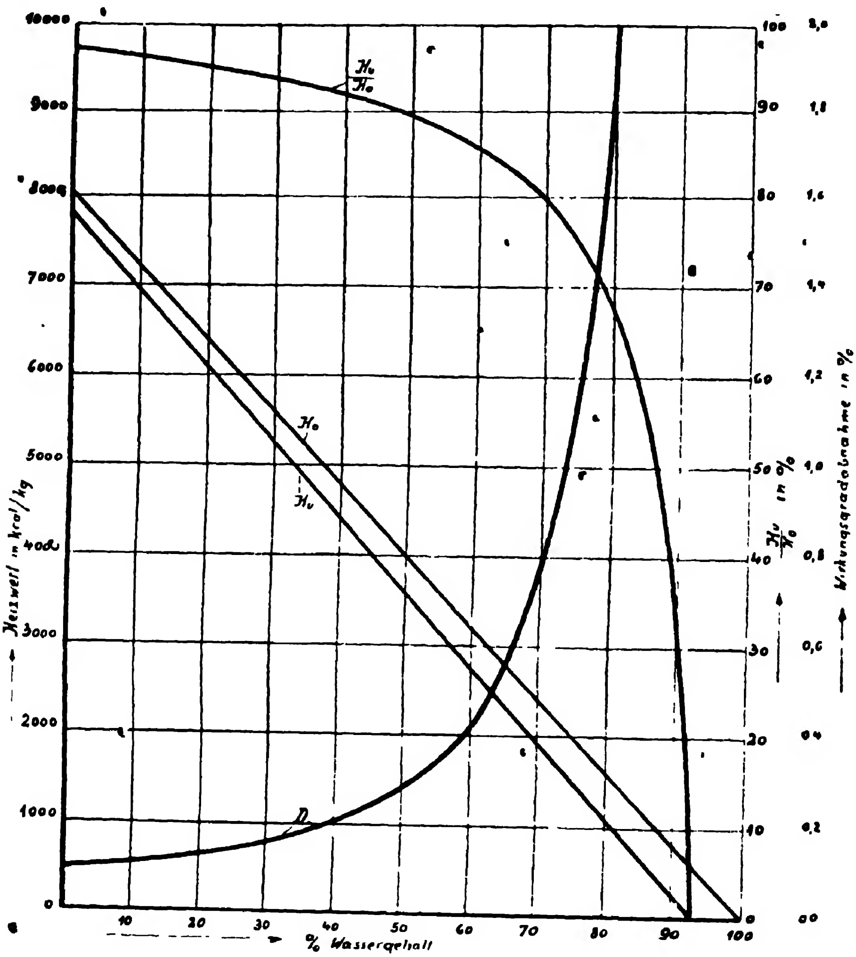

Abb 2.

H_o Verbrennungswärme (oberer Heizwert).
H_u Heizwert (unterer Heizwert).
$\frac{H_u}{H_o}$ Verhältnis: $\frac{\text{Heizwert}}{\text{Verbrennungswärme}}$.
D Zusätzliche Wirkungsgradabnahme in % durch Zugrundelegung der Verbrennungswärme bei Zunahme des Wassergehaltes um 1%.

Brennstoff habe, statt wie zugrunde gelegt einen Wassergehalt von 50%, einen solchen von 58 (in Wirklichkeit sind noch grössere Unterschiede möglich), so fällt der Wirkungsgrad um 4 Einheiten

niedriger aus als bei dem der Garantie zugrunde gelegten Brennstoff. Wäre also der Wirkungsgrad bei letzterem Brennstoff gerade erreicht, so würde sich beim Versuch nur 69% ergeben. Die in Deutschland übliche Toleranz von 5%, das sind in diesem Falle 3,65 Wirkungsgrad-Einheiten, wird also überschritten; dabei ist der eigentliche Zweck der Toleranz, nämlich die Aufnahme der

Abb. 3.

E Wirkungsgrad bei gleichbleibender Wärmedurchgangszahl für alle Wassergehalte bezogen auf den Heizwert.
F bezogen auf die Verbrennungswärme.

Messfehler, überhaupt nicht berücksichtigt. Im vorliegenden Falle kann die Abnahme also verweigert werden, obwohl die Anlage durchaus garantiegemäss arbeitet.

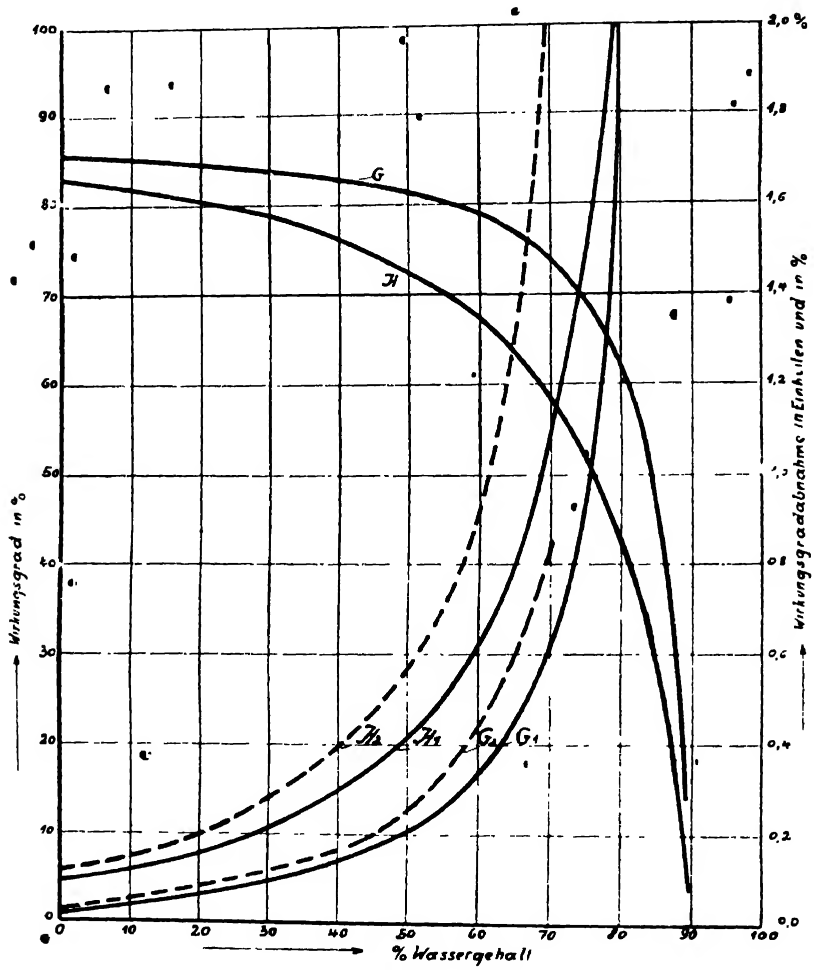

Abb. 4

G Wirkungsgrad bei gleichbleibendem Kessel bezogen auf den Heizwert.
H Wirkungsgrad bei gleichbleibendem Kessel bezogen auf die Verbrennungswarme.
G_1 Wirkungsgradabnahme in Einheiten bei Zunahme des Wassergehaltes um 1% und Zugrundelegung des Heizwertes
G_2 desgl. in % des jeweiligen Wirkungsgrades
H_1 Wirkungsgradabnahme, in Einheiten bei Zunahme des Wassergehaltes um 1% und Zugrundelegung der Verbrennungswärme.
H_2 desgl. in % des jeweiligen Wirkungsgrades.

THE USE OF GROSS AND NET CALORIFIC VALUES FOR THE PURPOSE OF GUARANTEE TESTS

(ENGLISH VERSION—ABRIDGED)

The method of expressing the value of any particular fuel varies widely in different countries. Not only are different weight and volume units employed, but the most important difference resides in the different methods used for expressing the calorific value of the fuel in question. The use of the gross calorific value for fuel evaluation presupposes that all the products formed by the combustion are cooled to 32 F. On the other hand, the net calorific value is based upon the assumption that the heat of condensation of the water vapour present in the combustion products is not available as a source of heat and is, therefore, subtracted from the gross value The use of the gross calorific value as the basis for fuel evaluation has the advantage that the exact meaning of the term is capable of easy explanation The net calorific value, on the other hand, is somewhat more obscure, as it presupposes that, while all the dry components of the combustion products are cooled to 32 F., the water vapour is only cooled down to its dew point, and that it entirely disappears from the calculation at this point. Owing to the fact that the term gross calorific value is capable of somewhat clearer and more exact explanation, there has been a tendency in many countries to adopt this unit as the basis for guarantee tests on power plants, etc.; it was officially introduced for testing purposes in Germany in 1925, but it was arranged that a two-year period should exist during which both terms should be used side by side This period has now expired and it is possible to state that the use of the gross calorific value as the basis for power plant tests, etc , has not been found to be entirely successful. Although no official decision has been reached, many institutions have entirely discarded the use of the gross calorific value and guarantees are only given, and asked for, on the basis of the net unit It has been clearly shown that when using fuels with widely varying contents of moisture, it is very important that the standard employed for comparison should be such as not to be influenced by differences in the free moisture content of the fuel in question. When employing the gross calorific value as the comparison, it is obvious that the entire issue becomes somewhat obscured by the fact that the water content of a fuel is allowed to influence the efficiency of the installation as such. The respective efficiencies of an installation based upon the gross and net calorific values of the fuel may to some extent be compared with the thermal and thermodynamic efficiencies of an engine. The thermal efficiency indicates the proportion of the total heat utilised in the form of work, the thermodynamic efficiency indicates the heat utilised in the form of work as a percentage of the total heat which could have been utilised for such work Of these, only the thermodynamic efficiency is of any importance when assessing the performance of an engine. The combustion efficiency based upon the net calorific value similarly ignores the heat value of a fuel which it is not possible to utilise technically Owing to the fact that the thermal and thermodynamic efficiencies differ from each other to a considerable degree, confusion is not likely to arise, but here the situation is somewhat different, when having to deal with plant efficiencies which are based upon the net and gross calorific value of fuels, as these values are not so widely separated and errors and confusion are, therefore, far more likely to arise. In order to make the exact meaning of the two terms (gross and net calorific value) somewhat clearer it has

been proposed in Germany to substitute for the gross calorific value the term "heat of combustion" and for the net calorific value the term "heating value." The use of the correct unit is also of great importance when buying fuels, as it is obviously important to base the value of the fuel upon the amount of heat which will be available for use, *i.e.*, upon the heating value, or in other words the net calorific value; for this reason only the net calorific value is used when buying and selling fuel in Germany. Two examples showing the unsuitability of the gross calorific value as the comparative basis for tests of heating installations working under different conditions are given below:

1. Fuel—Rhineland lignite.

Gross C.V.	2459 calories per Kg.
Net C.V.	2002 ,, ,,
Ash content	low
Efficiency based upon net C.V. ...	76 per cent.

2. Fuel:—Mixed coke breeze and culm.

Gross C.V	4692 calories per Kg.
Net C.V.	4491 ,, ,,

On account of the high ash content of this fuel, and of the high percentage of excess air necessary for its combustion, the efficiency of the installation based upon the net C.V. only reached 65 per cent. in this case.

If both examples are recalculated on the basis of their gross calorific values the picture becomes entirely different, and we find an efficiency in the first case of 62 per cent. and in the second case of 62·3 per cent. In other words, the efficiency of the second installation now becomes higher than of the first, in spite of the fact that the conditions under which the second installation operates are such that its actual efficiency must necessarily be lower. In the above examples the difference in gross and net calorific value was due to the high moisture contents of the lignite, but differences are also shown in cases where the water contents of the fuels under comparison are equal, as will be seen from the following example. Two classes of fuel are assumed to be burnt upon a travelling grate.

1 Coke containing 10·7 per cent. water.

Gross C.V.	6460 calories per Kg.
Net C.V.	6374 ,, ,,

2. Lignite briquettes also having a water content of 10·7 per cent.

Gross C.V.	5222 calories per Kg.
Net C.V.	4924 ,, ,,

In the first case the efficiency of the plant was somewhat low on account of the difficult conditions for combustion, and reaches only 79 per cent. The installation using lignite as fuel, on the other hand, has an efficiency of 81 per cent., both values being calculated upon the net calorific value of the respective fuels. If the efficiency is recalculated upon the gross calorific values as the basis, we find that the picture becomes reversed, in such a way that the coke fired installation now shows an efficiency of 78 per cent., while the second case, where lignite is burnt, the efficiency becomes 76·2 per cent. Should the coals used during the guarantee test on any heating installation have a moisture content different from that of the fuels on which the guarantees were based, the use of the gross calorific value as a comparative basis has also great drawbacks

GESICHTSPUNKTE FÜR DEN WIRTSCHAFTLICHEN VERGLEICH DER KALORIE IN GAS- ODER FESTER FORM

(POINTS OF IMPORTANCE FOR AN ECONOMICAL COMPARISON OF THE VALUE OF THE HEAT UNIT IN GASEOUS AND SOLID FUELS)

DEUTSCHER VEREIN VON GAS- UND WASSERFACHMÄNNERN

HR. ELVERS

Paper No. G4

CONTENTS

Die gewaltigen Umwälzungen, die das Wirtschaftsleben der ganzen Welt dadurch erfahren hat, dass ein Teil der früheren Agrarländer und manche Kolonialgebiete zu Industrieländern geworden sind, zwingen zu schärfster Erfassung aller nur erreichbaren Mittel zur Verbilligung in der Herstellung von Gütern aller Art.

Einen nicht ganz unerheblichen Anteil an den Gesamterzeugungskosten haben nun aber die Kosten für die Erzeugung von Kraft und *Wärme*.

Ausser der gesteigerten Wärmewirtschaft des Einzelbetriebes werden die Gesamterzeugungskosten dadurch verringert, dass man die Energien in grossen Einheiten erzeugt und in Form von elektrischem Strom oder Gas auf bedeutende Strecken den Einzelverbrauchern zuführt. Es ist hierbei zu fordern, dass auch die Elektrizität mehr und mehr unter vorheriger Zerlegung der Kohlen in Gas und Öl gewonnen wird. Dieser bereits beschrittene Weg führt die Ent- und Vergasung zu einer wichtigen Vorstufe der Elektrizitätsgewinnung.

Demnach ist eine rationelle Kraft- und Wärmewirtschaft durch Entgasung, Vergasung, Verschwelung usw. gegeben. So wies besonders das Jahr 1926 durch die internationale Kohlentagung zu

Pittsburgh der Brennstoffwirtschaft nicht nur verbesserte, sondern zum Teil neue Wege. Die alten Wege kennzeichnen sich durch die bekannten Methoden der Entgasung und Vergasung. Hierbei zeigte sich, dass beim Vergleich der Kalorie in Gas oder fester Form privatwirtschaftliche Vorteile oft nicht im Einklang mit der Gesamtwirtschaft stehen.

Die Kohle wird immer mehr aus einem Brennstoff zu einem Rohstoff, d.h. mit dem Ziele höchster Steigerung des Gesamtwirkungsgrades unserer Energiewirtschaft entfernt sich unsere Brennstoffwirtschaft immer weiter von der Verfeuerung roher Kohle und geht in immer grösserem Umfange zur Veredelung der Kohle über. Bei der gegenwärtigen Lage der Dinge entwickelt sich im Auslande wie auch im Deutschen Reiche die Kohleveredelung vor allem in organischer Verbindung mit anderen Verwendungsarten der Kohle in ein und demselben Gesamtbetriebe. Man kann beobachten, dass neuzeitliche Stahlwerke sich mit ihren Koks- und Hochöfen mehr als bisher nicht nur als Eisen- und Stahlerzeuger, sondern auch als Gasversorger betrachten.

Es bestehen gute Aussichten in neuen Verschwelungsverfahren von Kohlenstaub. Auf der internationalen Kohlentagung in Pittsburgh wurden diese Verfahren erwähnt. Unter anderem wurde auch von einer Verbindung von Schwelen und Brikettieren berichtet. Diese Tatsachen zeigen, wie sehr die Veredelung der Kohle nach der Seite der Verschwelung hin erwünscht ist.

Auch die Kohlenstaubtechnik hat grosse Erfolge aufzuweisen. Dieses mechanische Veredelungsverfahren (im Unterschiede zu dem chemischen) steigerte sich von 2½ Millionen t auf rund 4 Millionen t im Jahre 1926. Der Erfolg eröffnet besonders dem deutschen Braunkohlenbergbau Wege zur Schaffung eines neu veredelten Brennstoffes und dem Steinkohlenbergbau bessere Absatzmöglichkeiten für feinkörnige Kohle und Abfallsorten.

Die Entgasungs- und Vergasungsverfahren werden weiterhin übersteigert werden durch die neueste chemische Veredelung der Kohle. Bei Erwärmung der Kohle unter Luftabschluss erhält man Koks und Gas. Aus letzterem werden wertvolle Teere, Öle und andere chemische Erzeugnisse gewonnen. Seit ungefähr 150 Jahren hat die Energietechnik das Hauptbestreben, die Kohle durch Gas zu ersetzen. Dieses technische Ideal fand seine Begrenzung bis heute darin, dass bei den bisherigen Verfahren auf 100 bis 150 cbm Leuchtgas 150-250 kg Koks entfielen. Der Gasabsatz hängt also von dem Koksverbrauch ab. Die Eisenindustrie ist der grösste Abnehmer für Koks, deshalb wird in den Kokereien als

Hauptprodukt Koks erzeugt. Die Gaswerke stellen Gas als Hauptprodukt dar und bringen den Koks in Giessereien und Zentralheizungen unter. Beide Entwicklungen haben sich getrennt voneinander vollzogen. Die Nachfrage nach Gas und Koks kann in der Zukunft durch besondere Ausgleichungen von diesen beiden Gebieten aus befriedigt werden. Die steigende Energiewirtschaft hat aber gelehrt, dass die wertvollen Teere und Öle nicht in der erforderlichen Menge durch die bestehenden Entgasungsverfahren gewonnen werden können. Diesbezüglich sind die meisten europäischen Staaten von einer Öleinfuhr abhängig. Die immer brennender werdende Frage auf dem Ölmarkte zwang die bestehenden Verfahren der Hydrierung der Kohle oder die Öl-Synthese aus Kohlengasen und Wasserstoffen zur Vollendung zu bringen. 5 Wege stehen hierzu zur Verfügung·

(1) die Extraktion,
(2) die Urteergewinnung,
(3) die Hydrierung der Kohle,
(4) das Syntholverfahren,
(5) der Weg über die Karbide.

Die Verfahren der bahnbrechenden Forscher und Erfinder auf diesem Gebiete sind bestens bekannt.

Somit steht die Energiewirtschaft vor umwalzenden Ereignissen. Den Entgasungs- und Vergasungsmethoden schliessen sich in Zukunft in stärkerem Masse die Verschwelungs- und Verölungsverfahren an. Wie die Erfahrungen der Vergangenheit gezeigt haben, und wie die interessante Kohlentagung in Pittsburgh offenbarte, sind die vorgenannten Veredelungsverfahren der Kohle fur den wirtschaftlichen Vergleich bei der Bewertung der Kalorie in Gas oder fester Form von hervorragender Bedeutung.

Den allgemeinen gesamtwirtschaftlichen Gesichtspunkten schliessen sich die betriebswirtschaftlichen an.

Die Auswahl der richtigen Brennstoffe für die verschiedenen Wärmebehandlungsverfahren im Haushalte, im Gewerbe und in der Industrie ist stets mit Rücksicht auf das angestrebte Ergebnis in Bezug auf Güte und Gesamtkosten des Fertigerzeugnisses zu treffen. Es leuchtet ein, dass hierbei der reine Wärmepreis für eine bestimmte Wärmeleistung nur ein Faktor in der langen Reihe der Fragen ist, die für einen wirtschaftlichen Vergleich bei der Bewertung der Kalorie in Gas bzw. in festen und flüssigen

Brennstoffen oder in elektrischer Energie zu beantworten sind. Das Hauptproblem vom Betriebsstandpunkte aus gesehen liegt darin, hochwertige Erzeugnisse bei niedrigen Kosten zu erhalten. Die Auswahl des Brennstoffes sowie die Art der Feuerung muss immer diesen Gesichtspunkt berücksichtigen. Jede Auswahl der Brennstoffe, die sich lediglich auf einen Wärmepreisvergleich der verschiedenen Arten von Brennstoffen gegeneinander oder von Brennstoffen gegen elektrische Energie für einen Prozess stützt und scheinbare Vorteile des einen gegenüber dem anderen Verfahren aufstellt, führt unbedingt zu einem falschen wirtschaftlichen Ergebnis. Jede Brennstoffart hat ihr besonderes Anwendungsgebiet, aber auch ihre Begrenzungen. Die Anwendung der einzelnen Brennstoffarten richtet sich jeweils nach den speziellen Erfordernissen der Wärmebehandlung und unterscheidet sich in den verschiedenen Ofentypen mit den speziellen Wärmeausnutzungsmöglichkeiten, in den Betriebsverfahren, den Betriebsanforderungen und vielen anderen Faktoren, von denen jeder einen Einfluss bei bestimmten Bedingungen auf die Auswahl haben kann. Die ganze Frage bietet demjenigen, der sich mit der Auswahl von Ofenanlagen, etc., die für die bestimmten Anforderungen in Frage kommen, zu beschäftigen hat, grosse Schwierigkeiten. Man findet vielfach sich direkt widersprechende Anpreisungen über die Zweckmässigkeit der einzelnen Brennstoffarten bzw. der elektrischen Energie. Richtige Schlüsse kann nur der praktische Betrieb liefern. Genaueste Betriebsaufnahmen und eingehende Kalkulationen sind unbedingt erforderlich, um einen wärmewirtschaftlichen Vergleich bei der Bewertung der Kalorie in den verschiedenen Brennstoffarten ziehen zu können. Daneben aber wird immer die Wirtschaftlichkeit der Energieverteilung des Gesamtunternehmens und weiter des ganzen Landes, je nach den bestehenden Energiequellen, Berücksichtigung finden müssen.

Der betriebswirtschaftliche Vergleich der einzelnen Energien wird in starkem Masse bedingt durch die Verteilungskosten. Hier stehen sich die Energien Kohle, Öl und Gas mit folgenden Faktoren gegenüber. Bei der Verwendung des Öles tritt zu den reinen Ölkosten noch die Fracht, Umladegebühren, Kosten für Aufbewahrung und Verzinsung des im Ölvorrat festgelegten Kapitals. Zu diesen Kosten kommen noch Löhne für Pumpen, Reparaturunkosten, Verluste durch Undichtigkeiten, Verdunstung usw. Bei der Betrachtung der festen Brennstoffe bringt der Vergleich ähnliche Kosten. Es treten zum Preis ab Zeche für die Kohle noch die Fracht, Standgelder, Löhne für das Umladen, Verluste auf den

Kohlenlagerplätzen, die Kapitalverzinsung für die lange Lagerzeit der Kohle, bei grossen Anlagen Löhne für den Transport zum Ofen, Abschlacken und Aschetransport hinzu. Bei nicht durchgehendem Betriebe müssen die Öfen nachts bedient werden oder bedürfen einer langen Anheizzeit, sodass hierdurch ebenfalls mehr Kosten verursacht werden. In diesem Punkte ist die Wirtschaftlichkeit der Gasversorgung eine bedeutend günstigere. Durch die unmittelbare Entnahme des Gases als Brennstoff an den Feuerstätten wird an Betriebsgehältern und Betriebslöhnen gespart. Die oben benannten Frachten mit den verschiedenen zugeordneten Faktoren fallen fort. Die Ersparnis an Gehältern ist auf Grund vielfacher Berechnungen als ziemlich bedeutend festgestellt. Wenn auch die Kohlenfracht z.T. unter der Gasfracht liegt, so muss man hier eben die Ersparnis an Werksgehältern und Löhnen hinzurechnen. Hierin liegt die besondere volkswirtschaftliche Bedeutung der Gasversorgung.

Die Privatwirtschaft bevorzugte die Verwendung von Rohkohle zur Wärmeerzeugung ihrer scheinbaren Billigkeit wegen, sodass andere Ausnutzungsmöglichkeiten der Kohle bis vor kurzem wenig Beachtung fanden. Die Unannehmlichkeiten und Kosten, die durch die Anfuhr, die mangelnde Sauberkeit und die Lagerung der Kohle bedingt sind, wurden in Kauf genommen.

Die Aufgaben der Kohlewirtschaft müssten sein: mit weniger und geringwertiger Kohle mehr Wärme schaffen und die erzeugte Wärme besser ausnutzen. Bei der Verbrennung des festen Stoffes Kohle wird kostbare Wärme-Energie durch die schlechte Ausnutzungsmöglichkeit der Feuerungsanlage verschwendet. Es tragen manche Umstände zum Elend der Wärmewirtschaft bei, wie z.B. schlecht überwachte Gebäude-Heizungen, nicht ausgenutzte Abfallwärme von Maschinen, schlechte Verbrennung auf dem Rost, durch Falschregulierung des Zuges der Feuerung, Falschlufteinsaugung bei Ölen, wärmeundicht gebaute Häuser usw. Die 7 Gebote des Wärmehaushaltes sind somit folgende:

(1) gute Verbrennungsbedingungen herstellen,
(2) der Eigenart des jeweiligen Brennstoffes entsprechen,
(3) keine überflüssige Wärme erzeugen,
(4) Unverbranntes wieder verwenden,
(5) Feuerung und Ofen, Kessel und Herd pflegen,
(6) Wärme gut leiten,
(7) möglichst wenig Wärme verloren gehen lassen.

In jeder Beziehung werden diese 7 Punkte von der Gastechnik erfüllt. Bei der Verwendung des Gases als Brennstoff ist es möglich,

gute Verbrennungsbedingungen herzustellen, der Eigenart in jeder Weise zu entsprechen, keine überflüssige Wärme zu erzeugen, die Feuerung und den Ofen mit den einfachsten Mitteln zu pflegen; ist es möglich, die Wärme gut zu leiten und so den Wärmeverlust bis auf ein ganz geringes Mass zu vermindern.

Bei der Veredelung der Kohle wurde das Hauptgewicht auf eine weitgehende Gewinnung der Wärmekalorien in Form von Gas und Koks und in zweiter Linie erst auf die Gewinnung der Nebenprodukte als Teeröle, Ammoniak, Cyanverbindungen, Schwefel usw. gelegt. So beträgt die prozentuale Ausnutzung bei der Entgasung oder restlosen Vergasung der Kohle, dem Wärmewert nach gerechnet rund 80%. Würde man bei der Frage der Wärmeverwertung auch die Wärme des elektrischen Stromes mit 864 Kalorien in 1 kWh heranziehen, so gibt der Vergleich der Wärmeausnutzung der Kohle nur einen Prozentsatz von rund 15%. Das Verhältnis von 15 zu 80% ist in der Vergangenheit stets entscheidend gewesen und wird es trotz etwaiger besserer Ausnutzungsmöglichkeiten in den Anwendungsapparaten für die Elektrizität immer noch zu Gunsten des Gases bleiben.

Entscheidend fur die Einführung des Gases war die Möglichkeit, durch die Gasflamme eine höhere Wärmeintensität zu schaffen. Die Wärmeintensität wird vornehmlich in der Industrie gebraucht, ist aber auch von besonderer Bedeutung bei der Behandlung des Kochgutes mit Wärme im Haushalt. Es muss in einer bestimmten Zeit eine gewisse Wärmemenge durch den Kochtopfboden übertragen werden oder in kürzerer Zeit eine bestimmte Wärmemenge, z.B. beim Grillen, auf das Bratgut wirken. In diesem Falle ist eine bestimmte Temperatur der Flamme erforderlich, die nach gewissen Gesetzen reguliert werden muss. Bei der Kohleheizung ist dies nur unter Aufwendung von grösserer Aufmerksamkeit und Mühe möglich. Dies war ein weiterer wesentlicher Gesichtspunkt für die Einführung des Gases im Haushalt.

Die gleiche Frage musste gelöst werden bei der Verwendung der Wärme für Warmwasserapparate oder Heizöfen. Bei Warmwasserapparaten kam eine besondere Regulierfähigkeit noch wegen der verschiedenen Warmwasserbereitungen in Frage, wie z.B. Erwärmung des Wassers beim Durchfluss und auf Vorrat. Im ersten Falle muss in einer begrenzten Zeit eine reichliche Menge mit Sicherheit übertragen werden. Im zweiten Falle muss die Wärmezufuhr weitgehendst regulierfähig sein. Diese Bedingungen werden vom Gas als Brennstoff erfüllt, während feste Brennstoffe ihnen gar nicht und Öl nur unvollkommen genügen.

Für die Raumheizung gelten ähnliche Gesichtspunkte. Man hat zu unterscheiden:

(1) Dauerheizung, bei der regelmässig tagsüber wenigstens 12 Stunden oder mehr geheizt wird (z.B. Wohnräume).

(2) Periodische Heizung, bei der täglich nur während 6-10 Stunden geheizt wird (z.B. Büros, Schulräume usw.).

(3) Zeitweise Heizung, bei der nur gelegentlich und für kurze Zeit geheizt wird (z.B. Fremdenzimmer, Säle, Kirchen usw.).

Die Ansprüche, die diese verschiedenen Arten der Heizung an die Wirtschaftlichkeit stellen, können von der Heizung mit festen Brennstoffen nicht erfüllt werden, da eine so weitgehende Regulierfähigkeit bei ihr nicht zu erzielen ist. Dagegen ist man bei der Heizung mit Gas, gleichgültig, ob es sich um zentrale oder um Einzelheizung handelt, ohne weiteres imstande, jedem zu beheizenden Raume nur so viel Wärme und nur für die Zeit des wirklichen Bedarfs zuzuführen, wie für den gewünschten Zweck nötig ist.

Der Haushalt stellt an die Wärmeversorgung die Forderung der Zeitersparnis, der Sauberkeit, der Platzersparnis, der Hygiene und der Wirtschaftlichkeit.

Die Möglichkeit, mittels Gasfeuerung grosse Wärmemengen auf die zu beheizenden Kochflächen in kürzester Zeit zu übertragen, gewährleistet schnelles Kochen und gibt damit der Hausfrau die ihr so nötige Zeit, sich ihrer Familie zu widmen. Dagegen verlangt der Kohlenherd dauernde Beaufsichtigung und Arbeit; er entwickelt seine volle Leistung erst erhebliche Zeit nach dem Anheizen, das auch wieder Zeit kostet. Nach Beendigung des Kochens erfordert seine Reinigung ebenfalls wieder erhebliche Zeit, während der Gasherd mit ganz wenigen Handgriffen zu säubern ist.

Da der Brennstoff Gas für das Kochen, für die Warmwasserbereitung und für die Heizöfen seine Wärme direkt liefert, so ist die Platzersparnis und Sauberkeit damit gegeben. Mit der Sauberkeit wird eine grössere Hygiene erreicht. Mit Sauberkeit und Platzersparnis wird auch wieder Zeit gewonnen. Ausserdem kann man mit dem Brennstoff Gas durch seine gute Regulierfähigkeit viel Wärme sparen.

Es kommen also für den wirtschaftlichen Vergleich bei der Bewertung der Kalorie in Gas oder fester Form im Haushalt folgende Gesichtspunkte in Frage: Platzersparnis (keine Kohlenlagerung), Sauberkeit (kein Kohlentransport, keine Entaschung, kein Aschentransport), Bequemlichkeit (kein Kohlentransport, leichtere Bedienung), Zeitersparnis (schnelle Inbetriebsetzung, sofortige Heizwirkung, beste Regulierfähigkeit durch Temperaturregler usw.),

Anpassungsfähigkeit des Brennstoffes Gas an die Anforderungen der Wärmeübertragung und dadurch bedingte Ersparnis an Wärme, die ihrerseits wieder trotz höherer Kosten der Einheit doch ein wirtschaftliches Arbeiten gewährleistet.

Wir kommen nunmehr zu den Gesichtspunkten für den wirtschaftlichen Vergleich bei der Bewertung der Kalorie in Gas- oder fester Form in Gewerbe und Industrie

Bekanntlich ist nicht der Heizwert eines Brennstoffes und die Quantität der für einen Wärmeprozess erforderlichen Wärme ausschlaggebend, sondern die Intensität der Wärme, was ganz besonders bei Industriefeuerungen von grösster Bedeutung ist. „Es ist also zuerst die Frage aufzuwerfen, welche Temperatur ist für den betreffenden Arbeitsprozess nötig. Als Wertmesser für die *theoretische* Bewertung der Intensität kann die sogenannte Heizkraftzahl oder Wärmedichte dienen. Sie ist der Quotient aus dem unteren Heizwert und der Abgasmenge. Von ihrer Grösse hängt wieder die Höhe der Verbrennungstemperatur ab, welche den Quotienten darstellt aus Wärmedichte und spez. Wärme der Abgase. Es ist somit möglich, einen rein theoretischen Vergleich der Bewertung der Kalorie in den verschiedenen Brennstoffen zu ziehen; aber es leuchtet ein, dass diese theoretische Verbrennungstemperatur praktisch nicht erreicht werden kann; denn sie hängt von der Verbrennungsgeschwindigkeit ab, deren Grösse einmal in Wesen der einzelnen Brennstofftypen und dann auch in der Konstruktion der Feuerung und besonders der Brenner begründet liegt. Je schneller die Umsetzung der im Brennstoff ruhenden Energie in fühlbare Wärme stattfindet, desto mehr nähert sich die praktische Flammentemperatur der theoretischen Verbrennungstemperatur und umso grösser ist auch das nutzbare Wärmegefälle. Ein Masstab für die *Wirtschaftlichkeit* des Betriebes ist damit jedoch noch keineswegs gegeben. Mit Ausnahme des elektrischen Stromes als Wärmequelle ist für die Wärmelieferung bei festen, flüssigen und gasförmigen Brennstoffen der Gehalt an Kohlenstoff und Wasserstoff bzw. an Kohlenwasserstoffen massgebend. Bei den festen bitumenarmen Brennstoffen besteht die Kohlensubstanz in der Hauptsache aus reinem Kohlenstoff, während bei den Ölen der Kohlenstoff in mehr oder weniger komplizierter Verbindung mit Wasserstoff und anderen Elementen vorkommt. Zwischen beiden liegt die Reihe der jüngeren, bitumenreichen Kohlen (Braunkohlen). Bei diesen beiden Brennstofftypen muss der Verbrennung zunächst eine

Ent- bzw. Vergasung vorausgehen, bis, wie bei den Heizgasen, der Kohlenstoff bzw. die Kohlenwasserstoffe in einfachster Form neben Wasserstoff zur Verbrennung vorliegen. Hieraus erhellt, dass die Verbrennungsgeschwindigkeit bei den Gasen am grössten sein muss. Je grösser die Verbrennungsgeschwindigkeit und je kürzer die Flamme, desto grösser ist die Wärmeintensität und damit die Flammentemperatur. Das Ideal der Verbrennung ist hiernach: Freiwerden der Wärme in kürzester Zeit im kleinsten Raum. Eine hohe Verbrennungsgeschwindigkeit bei kohlenstoffhaltigen Gasen kann daher nur erreicht werden bei innigster Gasluftmischung vor dem eigentlichen Ofenraum.

Für die Eignung eines Gases als dem wärmetechnisch vorteilhaftesten Brennstoff für eine bestimmte Wärmebehandlung ist neben der Art der Verbrennung und Flammenbildung noch die Art der entstehenden Verbrennungsgase bestimmend. Wasserstoff mit einem Heizwert von 2 590 WE/cbm ergibt z.B. mit reinem Sauerstoff verbrannt bereits eine Stichflamme von solcher Temperatur, dass man damit autogen schweissen und schneiden kann. Die Ursache liegt in der Schnelligkeit des Verbrennungsvorganges. Dabei enthalten die Abgase lediglich Wasserdampf, der eine sehr hohe spez. Wärme hat und z.B. im kg etwa doppelt so viel Wärmeeinheiten enthält wie Kohlensäure von der gleichen Temperatur. Zugleich hat der Wasserdampf eine hohe Wärmeleitfähigkeit, sodass die Wärme aus der sehr kurzen Arbeitsflamme schnell in die Umgebung abfliesst. Autogenes Schweissen und Schneiden wäre z.B. mit Generatorgas vollkommen unmöglich, infolge der langsamen Flammenbildung, die nicht nur eine Folge des Stickstoffballastes, sondern vor allem auch des hohen Kohlenoxydgehaltes ist. Ein Gas mit einem hohen Kohlenoxydgehalt hat infolge der niedrigen spez. Wärme der gebildeten Kohlensäure eine lange Flamme, und die Verbrennungsgase verteilen infolge ihrer geringen Wärmeleitfähigkeit die Wärmeabgabe auf eine grössere Fläche. Für die Erzielung einer gleichmässigen Wärmeverteilung im Ofenraum haben Gase mit vorwiegendem Kohlenoxydgehalt daher eine gewisse Überlegenheit.

Für die Beurteilung der *Wirtschaftlichkeit* eines Brennstoffes sind für jeden Einzelfall der Wärmebehandlung nachstehende Fragen zu beantworten:

(1) Hängt von der Einhaltung einer ganz bestimmten Temperatur die Güte des Erzeugnisses ab?

(2) Ist eine ganz bestimmte Ofenatmosphäre für den betreffenden Prozess erforderlich?

(3) Durch welche Brennstoffart ist die grösste Ofenleistung zu erreichen?

(4) Sind Ersparnisse an Raum (z.B. durch Zusammenlegen von Ofen und Hammer bei Einführung der Gasfeuerung anstelle der Kohlenfeuerung) und dadurch Lohn- und Zeitersparnisse zu machen?

(5) Wie stellen sich die Brennstoffkosten am Ofen im Vergleich zu den Gesamtkosten der Erzeugung und dem Verkaufspreise?

Es kann allgemein gesagt werden, dass sich die gasförmigen und flüssigen Brennstoffe den modernen Arbeitsmethoden in Gewerbe und Industrie besser als die festen Brennstoffe anpassen.

Wenn es sich z.B. um die Warmbehandlung zahlreicherer kleiner Teile handelt, bei denen die Brennstoffkosten nur einen kleinen Bruchteil der Gesamtkosten betragen, und bei der es in erster Linie auf Qualitätserzeugung durch eine gleichmässige Erwärmung und genaueste Temperatureinhaltung ankommt (z.B. Härten von Werkzeugstählen), so kommt als Wärmequelle Gas in erster Linie in Frage. Kohle wird nur dann wirtschaftlich als Brennstoff verwendet werden, wenn es sich um Rohbearbeitung handelt, bei der eine Verzunderung nicht von Bedeutung, oft sogar erwünscht ist.

Die Temperaturregelung, die bei gewissen Industrieöfen, besonders solchen zu Härtezwecken und beispielsweise zum Glühen von Dynamoblechen sehr wichtig ist, wird bei Brennstoffarten veränderlicher Beschaffenheit sehr erschwert. Dies ist einer der wichtigsten Gründe dafür, dass in den letzten Jahren die Anwendung der Gasheizung so grosse Fortschritte gemacht hat, trotzdem die Heizkosten bei diesem Brennstoff, auf die reine Wärme bezogen, viel höher sind als bei festen Brennstoffen

Bei sehr vielen Prozessen in der Metallindustrie ist es nicht allein von Wichtigkeit, die Temperatur im Ofeninnern genau zu regeln, es ist häufig von ebensolcher Wichtigkeit, auch die Einhaltung einer ganz bestimmten Ofenatmosphäre zu gewährleisten, z.B. Blankglühen, Härten von hochwertigen Stählen in reduzierender Atmosphäre zur Verhütung von Zunderbildung. Bei Kohle- bzw. Ölfeuerung ist die Einhaltung einer reduz. Ofenatmosphäre wegen der damit verbundenen Russbelästigung ausgeschlossen. Für diese besonderen Zwecke eignet sich die Gasfeuerung ganz vorzüglich, und die Kalorie kann für diese Prozesse in Gasform weit mehr kosten als bei festen bzw. flüssigen Brennstoffen. Bei der Anwendung der Verfahren zur Temperatur- bzw. Ofenatmosphärenregelung hängt der Erfolg davon ab, dass Druck und Zusammensetzung des Brennstoffes gleich sind Das ist am leichtesten zu erreichen bei

gasförmigen Brennstoffen, schwerer bei flüssigen, und die festen Brennstoffe scheiden hierbei vollkommen aus.

Dagegen ist bei der Wärmebehandlung von Blechen z.B. eine wasserdampfhaltige Ofenatmosphäre notwendig, damit die Blechoberfläche mit einer gleichmässigen dünnen Zunderschicht für die darauf folgende Walzperiode bedeckt wird. Derartige Prozesse können in den meisten Fällen am wirtschaftlichsten mit festen Brennstoffen, die neben dem Wasserstoff und Kohlenwasserstoffgehalt eine gewisse Feuchtigkeit haben, durchgeführt werden.

Was nun die Grösse der Ofenleistung betrifft, so kann gesagt werden, dass diese bei den gasbeheizten Industrieöfen infolge der Möglichkeit einer sehr grossen Wärmebelastung des Ofenraumes gegenüber der Kohlenheizung sehr gesteigert werden kann. Es muss weiterhin berücksichtigt werden, dass es mit Gas leichter ist, die Wärme auf einen Punkt zu konzentrieren als bei der Kohlenheizung, zumal bei dieser in sehr vielen Fällen der industriellen Warmbehandlung eine indirekte Beheizung unbedingt notwendig ist. Es ist hierdurch möglich, nicht nur Wärme zu sparen, sondern auch durch die weit höhere Wärmeintensität bei der direkten Gasfeuerung die Ofenleistung sehr zu steigern.

Ein weiterer Punkt ist bei der Beurteilung der Wirtschaftlichkeit der einzelnen Brennstoffarten zu berücksichtigen. Der gasgefeuerte Ofen benötigt einen weit geringeren Raum als der Kohlenofen und bringt keinen Schmutz oder Staub in den Aufstellungsraum, wodurch es z.B. möglich ist, die Feuerstätte in allernächster Nähe der Maschine, Hammer, Presse aufzustellen. Hierdurch ist neben Ersparnis von Leuten (Zubringer) und Lohnkosten eine weit höhere Leistung des Aggregates möglich.

Der Preis einer bestimmten Wärmemenge im Ofen spielt wirtschaftlich natürlich eine grosse Rolle, tritt jedoch mit der Erzeugung hochwertigen Materials mehr und mehr in den Hintergrund gegenüber den oft weit höher zu bewertenden Vorteilen einer bestimmten zur Qualitätserzeugung erforderlichen Feuerungsart.

Bei wirtschaftlichen Kalkulationen wird meistens den Nebenkosten, die die einzelnen Brennstoffarten verursachen, zu wenig Beachtung geschenkt. So zergliedern sich z.B., wie schon weiter oben kurz erwähnt, die Kosten bei *festen Brennstoffen* in: Preis ab Zeche, Fracht, Standgeld, Löhne und Abschreibung sowie Reparaturkosten der maschinellen Einrichtungen zum Umladen, Wert des Kohlenlagerplatzes auf Hof und am Ofen, Versicherung der Kohle, Kapitalverzinsung für Brennstoffvorrat, Löhne für Transport zum Ofen, Abschlacken und Aschetransport. Hinzu kommt bei nicht

durchgehendem Betriebe die Bedienung der Öfen, während der Nachtzeit bzw. Anheizen lange vor Schichtbeginn.

Zu den reinen *Ölkosten* kommt hinzu: Fracht, Verlust durch Leckage und Verdunstung sowie Schlamm und geringen Wassergehalt, Umladen, Löhne und Dampf zur Erwärmung des Öles im Winter, Kosten für Aufbewahrung und Verzinsung des im Ölvorrat festgelegten Kapitals, Löhne für Pumpen, Kosten für Reparatur und Ersatzteile der Pumpeneinrichtungen, Unterhalt der Brenner, Löhne und Materialkosten für Ofenausbesserungen, die weit höher sind als z.B. bei der Gasfeuerung, Produktionsausfall bei Betriebsstörungen, da die Ölbrenner oft verstopft sind.

Bei den *gasförmigen Brennstoffen* sind dagegen nur die Leitungskosten von der Stelle der Erzeugung bis zum Ofen sowie die mechanischen und evtl. die kalorischen (Heissgas-Generator) Leitungsverluste zu berücksichtigen.

Diese einerseits rein technischen und die wirtschaftlichen Vor- bzw. Nachteile auf der anderen Seite müssen für jeden einzelnen Fall des industriellen Energiebedarfs zur Wärmebehandlung gegeneinander abgewogen werden.

Der Wärmewirkungsgrad der Industrieöfen für die verschiedensten Prozesse der Wärmebehandlung ist gewöhnlich sehr niedrig und liegt im allgemeinen zwischen 10 und 30%. Begründet liegt das darin, dass die Heizgase ihre Wärme nur solange abgeben können, als ihre Temperatur höher liegt als die des zu erwärmenden Ofeneinsatzes. Die Hauptwärmeverluste entstehen daher durch die hohen Abgasverluste, die in dem jeweils erforderlichen hohen Arbeitstemperaturen begründet liegen.

Es ist einleuchtend, dass man bemüht ist, den Wärmewirkungsgrad der Öfen auf das grösstmögliche Mass zu verbessern. Es stehen hierfür folgende Wege offen: Vorwärmung des Einsatzes, Vorwärmung der Verbrennungsluft oder des Brennstoffes oder von beiden, Verwertung der Ofenabhitze in Abhitzekesseln, gute Isolierung, richtige Wahl der Grösse des Verbrennungsraumes, dem Brennstoff entsprechend, und richtige Dimensionierung des Ofenraumes für die betreffende Materialgrösse. Bei den industriellen Öfen mit Gasfeuerung ist ein erheblich höherer Wirkungsgrad zu erreichen als bei Öfen mit Kohlenfeuerung. In einem gasgefeuerten Schmiedeofen erreicht man z.B. Wirkungsgrade von 20 bis 25%, während im Kohlenschmiedefeuer nur Nutzwärmen von 4 bis 8% erhalten werden.

Im folgenden sei noch auf die Dampferzeugung im Gross- und Kleindampfkessel eingegangen.

Durch die Einführung des Hochdruckdampfes infolge der dadurch gegebenen wärmewirtschaftlichen Vorteile war es nötig, auch die Feuerung derartiger Kessel zu verbessern und neue Beheizungsarten einzuführen. Hoher Dampfdruck ist untrennbar mit hoher Dampftemperatur verbunden. Hohe Dampf- und Wassertemperaturen verlangen hohe Feuerraumtemperaturen. Die wirtschaftlichen Vorteile, die hiermit verbunden sind, sind die relativ billigeren Herstellungskosten des Dampfes, relativ kleinerer Raumbedarf, geringere Wärme- und Bedienungskosten. Für Grossdampfkessel hat die Kohlenstaubfeuerung raschen Eingang gefunden; obwohl zur Ausbildung der Flamme ein grösserer Verbrennungsraum nötig ist, so bewirkt doch die Wärmestrahlung der in den Flammengasen schwebenden glühenden Kohlenstoffteilchen eine Leistungssteigerung. Die Kohlenstaubfeuerung kann als grosser energiewirtschaftlicher Fortschritt der Neuzeit bezeichnet werden, da minderwertige Feinkohle und sonstige Abfallkohle, die sonst schwer wirtschaftlich auszunutzen sind, zu sehr billigen Preisen bezogen werden können. Für Industriedampfkessel hat im allgemeinen die selbsttätige Rostfeuerung im Gegensatz zu den Kesselanlagen der Grosskraftwerke ihre Bedeutung beibehalten, da sich die Anlagekosten für Kohlenstaubkessel und die erforderlichen Mahlanlagen erst von gewissen Grössen ab lohnen. Neben der Rostfeuerung nimmt in industriellen Betrieben Generatorgas zur Beheizung von Kesseln eine dominierende Stellung ein. Durch die höheren Verbrennungstemperaturen des Generatorgases gegenüber festen Brennstoffen ist es möglich, eine Leistungssteigerung pro qm Heizfläche zu erzielen, ohne Verringerung des Wirkungsgrades gegenüber dem bestmöglichen Wirkungsgrad bei Rostfeuerung. Durch die hohe Anfangstemperatur und Erhöhung der Brenngeschwindigkeit ist die Vorwärmung von Gas und Luft wirtschaftlich möglich, ohne die Abgastemperatur über das gebräuchliche Mass zu steigern. Der Fortfall von Anheiz- und Abbrandverlusten ermöglicht namentlich bei Kesseln, die nicht sehr lange Zeit in Betrieb sind, recht belangreiche Ersparnisse an Wärme und damit Verbesserungen des Wirkungsgrades.

Für Beheizung von Gebäuden, Erwärmung von Flüssigkeiten, in Wäschereien, kleinen chemischen Betrieben, zum Betrieb von Maschinen in Gewerbe und Industrie sind noch immer vornehmlich Kesselanlagen mit Kohle- bzw. Koksfeuerung in Betrieb. Die Tendenz geht jedoch dahin, gerade für diese kleinen Betriebe Kessel mit Leuchtgasfeuerung aufzustellen. Die Vorteile dieser gasgefeuerten Kessel liegen einmal in dem erhöhten Wirkungsgrad

gegenüber der Verfeuerung fester Brennstoffe, dann in der guten Regulierbarkeit und der Anpassung an den jeweiligen Dampfbedarf, in der sauberen und hygienisch einwandfreien Anlage, in der schnellen Betriebsbereitschaft ohne Anheizverluste, der einfachen Bedienung und dem geringen Platzbedarf. Die Bedienungskosten der Feuerung mit festen Brennstoffen, sowie die Kosten für Lagerung des Kohlenvorrates, Transportkosten usw. fallen weg. Auch kann der gasbeheizte Kessel vielfach in dem Raum der Dampfverwendung Aufstellung finden (z.B. Wäscherei), was wegen der Staubentwicklung beim kohlenbeheizten Kessel unmöglich ist.

Zum Schlusse seien noch einige Beispiele der Bewertung der Kalorie in den verschiedenen Brennstoffen für das Gewerbe gegeben. Erfahrungsgemäss beträgt in der *Fleischerei* bei der Beheizung der Wurstkessel mit Kohle der Ausschuss 2-3%, während bei der Gasheizung ein Verlust von höchstens 1% eintritt. Die durch die Einführung der Gasfeuerung zu erzielende Ersparnis ist so gross, dass der Gaspreis nur eine untergeordnete Bedeutung hat.

Auch in der *Bäckerei* und *Konditorei* hat das Gas schon an vielen Stellen Eingang gefunden. Als besondere Vorteile der Gasfeuerung auf diesem Gebiete gegenüber der Benutzung fester Brennstoffe sind zu nennen: Wegfall des Kohlenkellers, des Heizraumes und des Schornsteines, was gerade hier wegen Fortfalls des durch feste Brennstoffe bedingten Staubes und sonstigen Schmutzes nicht zu unterschätzen ist. Weiterhin braucht ein Bäckermeister, der einen Gasofen besitzt, diesen nicht schon abends vorzuheizen, auch hat er seine Sonntagsruhe, die der Besitzer eines Kohlenofens nicht in vollem Masse geniessen kann. Als besondere backtechnischen Vorteile des Gasofens sind zu erwähnen: schnellstes An- und Nachheizen des Ofens (Ofen wird mit Teigbereitung gleichzeitig betriebsfertig), ferner die Eignung des oberen und unteren Herdes für jede Gebäckart. Der Bäckermeister, der seinen Betrieb auf Gas umgestellt hat, empfindet es weiterhin als sehr angenehm, die Rechnung für Brennstoffe nicht auf einmal bezahlen zu müssen, wie es bei der Einlagerung fester Brennstoffe der Fall ist, sondern er zahlt seine Gasrechnung nachträglich monatlich. Der Raumbedarf für den Gasofen ist weit geringer als der für den Kohlenofen. Ausserdem können in dem Gasofen bequem die Gärräume untergebracht werden.

Die Vorteile schnellen Anheizens machen sich auch in den *Trocken- und Lackierbetrieben* mit Gasfeuerung gegenüber denen mit festen Brennstoffen bemerkbar. Durch die geringere Wärmespeicherung ist es möglich, neben einem weit rascheren Arbeiten auch die bei

verschiedenen Lacksorten verschieden hohen Temperaturen ohne grosse Wärmeverluste rasch zu erreichen, womit eine Leistungssteigerung und damit Ersparnisse an Lohn- und Betriebskosten verbunden sind. Die Möglichkeit der Temperaturregelung bei derartigen Prozessen lässt die Gasfeuerung bei grossen kontinuierlichen Trocken- und Lackieröfen (Anheiz-, Trocken- und Abkühlzonen im Tunnel) gegenüber der Beheizung derartiger Öfen mit festen Brennstoffen sehr vorteilhaft erscheinen.

POINTS OF IMPORTANCE FOR AN ECONOMICAL COMPARISON OF THE VALUE OF THE HEAT UNIT IN GASEOUS AND SOLID FUELS

(English Version—Abridged)

INTRODUCTORY

The radical changes in methods of production which have recently taken place throughout the entire world, make it imperative to utilise all available means for reductions in costs of manufacture. A considerable portion of the total cost of production is represented by the generation of heat.

Coal has more and more come to be regarded as a raw material instead of only as a fuel, and, as the efficiency of the generation of energy has reached a higher level, the use of raw coal for firing has diminished and increasing endeavour is made to utilise coal in other directions. It is to be noted, for instance, that modern steel works' practice does not only regard itself as the producer of iron and steel but also as providers of gas. The International Fuel Conference in Pittsburgh during 1926 showed that great advances have been made in the field of fuel economy.

Some of the new methods for low-temperature carbonisation of pulverised coal appear to hold promise. A combined method of low-temperature carbonisation and briquetting of such fuel was also referred to. Great advances have been made in the field of pulverised fuel firing. The consumption of pulverised fuel for this purpose rose in 1926 from 2½ to 4 million metric tons. The newer chemical methods of coal treatment have also recently made very great advances. It was found that valuable tars and oils as produced by the usual methods of carbonisation, etc., were not available in sufficient quantities and, as a consequence, most of the European countries were dependent upon importation for their oil supplies. Methods for the hydrogenation of coals were devised to overcome this shortage. The choice of the correct fuel in industry and the household is of great importance. It is obvious, however, that the mere cost of the heat unit as such is only one factor in a long series of considerations. The chief problem from the industrial point of view is to obtain higher efficiency at a low cost. Each class of fuel has its special uses in special fields, but also its specific limitations. The use of any particular fuel is dependent upon the special requirements of each case and varies with the different types of furnace constructions and with the different possibilities for heat utilisation.

In the comparison of the different sources of energy, the cost of distribution is of the greatest importance. When using oils, freight, handling, storage interest and depreciation must be added to the cost of oil itself. To this cost must, furthermore, be added costs for pumping, repairs, losses by evaporation,

etc.; considering solid fuels, somewhat similar expenses must be considered. On all these points, the use of gas as a fuel shows up to much greater advantage. By taking the gas direct to the point of firing, great saving is effected by the absence of storage costs; cost of freight is also done away with.

The apparent cheapness of coal was the deciding factor in its selection for use in smaller industries, and its drawbacks were not taken into consideration.

The great problem of heat engineering must be to obtain more heat with less and poorer coal and to utilise the heat so created to a greater advantage. By the combustion of raw coal, large amounts of valuable heat energy are lost through the low efficiency of the installations. Some of the factors which are responsible for this low efficiency are badly supervised heating installations, lack of utilisation of waste heat from engines, etc., and inefficient combustion on the grate by indifferent control. The chief points of importance for the effective utilisation of heat are the following:—

1. Good conditions for combustion must exist.
2. These conditions must be regulated for the particular fuel in question
3. Avoidance of the generation of unnecessary heat.
4. Utilisation of unburnt fuel
5. Attention to grates, furnaces, boilers, etc.
6. Efficient distribution of heat.
7. Lowest possible heat losses.

The above seven points are all fulfilled by the utilisation of gas for firing. In the older methods of working up coal, the chief attention was paid to the conservation of the heat units in the form of gas and coke, and only secondary consideration was given to the yields of by-products, such as tar, oils, ammonia, cyanides and sulphur, etc.

A deciding factor for the introduction of gas for firing was the possibility of obtaining higher heat intensities. This advantage is especially made use of in industry, but is also of importance in the household. It is highly desirable that the temperature of the flame should be constant and also that the quantity of heat required for any specific purpose should be easily regulated When using coal, regulation is very difficult. Such ease of regulation is especially necessary in hot water installations (geysers, boilers, etc.). The varying requirements for the heating of buildings are not taken care of by the use of solid fuel owing to the lack of easy regulation associated with this. On the other hand, the use of gas is ideal for this purpose. In the household it is necessary that the method of heating utilised shall be time-saving, cleanly, and that the heating installation itself shall not occupy too much room, and here again the use of gas fulfils all demands. The use of a coal fire, on the other hand, demands constant attention and much work. The coal fire only reaches the maximum efficiency a considerable time after the fire has been lit and also compares unfavourably as far as cleanliness is concerned.

Comparison of the Thermal Unit in the Form of Solid or Gaseous Fuel in Industry

As is well known, the most important factors in a given case are not the calorific value of a fuel and the quantity of heat required for any specific process, but the intensity of heat which it is possible to reach. This is of special importance in industrial practice. The first question which must be asked must therefore be—What temperature is required for the process in

question? As a measure for the theoretical valuation of the heat intensity may be used the so-called *heat density*, which is expressed by the net calorific value divided by the volume of waste gases. Upon this figure depends the flame temperature; it is consequently possible to obtain a basis for a purely theoretical comparison of the valuation of the heat unit in different fuels. It is obvious, however, that such theoretical flame temperatures cannot be reached in actual practice, because first of all this temperature depends on the speed of combustion, which in turn is dependent upon the properties of different fuels, and also upon the specific construction of the furnace and burner equipment. The quicker the energy stored in the fuel is transformed into sensible heat the nearer the flame temperature obtained in practice will approach the theoretical flame temperature. With the exception of electric current as a source of heat, the yield of heat energy is dependent upon the current of carbon, hydrogen and hydrocarbons in the fuel. In bituminous fuels the coal substance is composed mainly of pure carbon, whereas in the case of oils the carbon is generally present associated with hydrogen and other elements in the form of complicated compounds. In both these types of fuel the combustion must be preceded by a distillation or gasification process, until, as is the case with gaseous fuels, the carbon and hydrocarbons are present as simple compounds. From this it follows that the rate of combustion must be greatest with gaseous fuels; the greater the rate of combustion and the shorter the flame, the greater is also the heat intensity, and consequently the flame temperature. The ideal conditions for combustion must consequently be those in which the liberation of heat takes place in the shortest possible time and within the smallest possible space. High rates of combustion can only be obtained in the case of carbon-containing gases by an intimate mixture of the gas and air before it arrives in the furnace chamber. Apart from the combustion itself and the flame conditions, the quality of the products formed by the combustion is also of importance for the successful use of a gaseous fuel for any specific purpose. Hydrogen with a C.V. of 2,590 calories per cu. metre gives, for instance, when burnt in pure oxygen, a short flame of such temperature that it can be used for welding and cutting. The reason for this is the high speed of combustion. The combustion products contain water vapour, the specific heat of which is high and which contains per unit weight twice as many heat units as, for instance, CO_2. The water vapour has also a high conductivity, so that the heat soon flows from the short flame into the surroundings. To utilise producer gas for welding and cutting would be entirely impossible on account of the slow flame propagation, which is not only a direct consequence of the load of inerts associated with this gas, but is also dependent upon the high CO_2 content. A gas with a high CO content has, as the result of the low specific heat of the CO_2 formed, a long flame and the combustion products, as a result of their low conductivity, dissipate their heat over a greater area. For obtaining an even heat distribution in a furnace chamber, it is advantageous to use gases with a high content of CO. In order to form an opinion as to the suitability of a fuel for any particular purpose the following questions must be answered:—

1. Is it of importance that an absolute even temperature be maintained?
2. Is a kiln atmosphere of a definite composition necessary for the process in question?
3. Which type of fuel will give the highest kiln efficiency?

4. Are savings in space, wages and time, of importance?
5. What is the proportional cost of the fuel to the total production costs and sales price?

It can be stated generally that gaseous and liquid fuels are more suited to modern works conditions than is a solid fuel. For instance, when heat treatment of numerous small parts comes into question, by reason of which the cost of fuel only amounts to a very small part of the total cost, and where it is important to produce goods of first-class quality by means of the finest possible temperature regulation, gas as a source of fuel must come first of all into consideration. Under such conditions coal can only be utilised as fuel for the treatment of the raw material The need of fuel which will give an easily controllable temperature is one of the reasons why gas firing for industrial purposes has made enormous progress in recent years, in spite of the fact that the cost of heating, when calculated back to the pure cost of the heat unit, is very much higher with gas than with solid fuels In some industries it is not only important to maintain a constant furnace temperature, but also that a furnace atmosphere of a certain composition shall be maintained When using coal and oil it is impossible to maintain a reducing atmosphere owing to the formation of soot, and for such conditions the use of gas is especially advantageous, and it is therefore permissible to utilise a heat unit costing considerably more than units generated by coal and oil If automatic means for the regulation of furnace temperature and atmosphere are utilised, it is essential for the successful operation of the control device that both fuel pressure and composition remain constant Such constant conditions are easily obtained by use of gas for firing, with oil such constant conditions are reached with greater difficulty, and with solid fuels they are almost impossible to attain. In certain other forms of heat treatment a furnace atmosphere containing water vapour is necessary, for instance, in the manufacture of iron and steel plates, etc Such material is advantageously treated by means of firing with solid fuels.

As far as the efficiency of the furnace is concerned, it may be stated that gas-fired industrial furnaces generally work at a higher efficiency than do similar coal-fired furnaces It must also be taken into consideration that when firing with gas it is easier to concentrate the heat on to one particular point than would be the case if coal firing were used A further point of importance, when assessing the suitability of a certain type of fuel, is the point that a gas-fired furnace needs much less room than one fired with coal, and that a gas fire is free from dirt and dust, whereby it is possible to arrange the furnace close to the machinery and plant, thus making the saving of labour possible

The cost of a certain quantity of heat is, of course, of great practical importance, but this point is rapidly becoming less important with valuable material, and when other advantages of a type of firing which yields goods of constant quality is taken into consideration The efficiency of industrial furnaces when operating on various heat treatment process is generally very low, and usually lies between 10 to 30 per cent The reason is that the heating gases can only give up their heat to the goods so long as their temperature is higher than the goods to be heated. The chief sources of heat losses are, therefore, associated with the combustion gases This efficiency may be raised by attention to the following points :—

1. Pre-heating of the goods.
2. Pre-heating of fuel and or air.
3. Utilisation of the waste heat from the furnace.
4. Proper insulation.
5. Correct measurements for the furnace and combustion chamber.

The efficiency of gas-fired industrial furnaces is generally higher than with similar furnaces fired with coal.

GENERATION OF STEAM

The introduction of high-pressure boilers necessitated improvements in the methods of firing. High steam pressure is necessarily associated with a high steam temperature. High steam and water temperatures require high firing temperatures. For boilers of large size, firing by means of pulverised fuel has made great strides in spite of the fact that this type of firing requires larger combustion chambers. The presence of suspended incandescent particles in the stream of combustion products increases the overall efficiency due to radiation. The firing by means of pulverised fuel may be taken as a great industrial advance, especially in view of the fact that low-value finely divided fuels, otherwise difficult to dispose of, can be utilised.

For smaller industrial installations the coal fired grate is still holding its own, owing to the high installation costs associated with pulverised fuel firing, which is therefore, only economical in installations above a certain size.

The heating of boilers by means of producer gas is also of great importance on account of the higher flame temperature associated with producer gas as compared with solid fuels. By the use of producer gas it is possible to obtain greater efficiency per unit area of heating surface. Pre-heating of fuel and air is also possible, and economical, without increasing the temperature of the waste gases above those which are usual. The absence of starting up, and clinker losses, especially with boilers which are not in use over a prolonged period, also tend to increase the overall efficiency when gaseous fuels are used. For heating buildings, in laundries and small chemical factories, coal and coke fired boilers are still in extensive use, but the tendency has grown to utilise town's gas for such purposes. The utilisation of gas for firing is of special importance in certain trades, such as bakeries etc., where great cleanliness is necessary.

Gas firing is also very advantageous in varnish works, as the different temperatures required for the different kinds of varnishes can quickly be obtained.

THE BY-PRODUCT COKE OVEN AS A SOURCE OF INDUSTRIAL AND DOMESTIC ENERGY

THE JOINT FUEL COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS, THE SOCIETY OF CHEMICAL INDUSTRY, THE COKE OVEN MANAGERS' ASSOCIATION, AND THE INSTITUTE OF FUEL

C. P. FINN AND R. RAY

Paper No. G5

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INTRODUCTION

The exploitation of the various sources of energy available to man extends and progresses as his requirements—industrial and domestic—expand. That which sufficed for one generation is inadequate for the next, and the luxury of to-day becomes the necessity of ten years hence.

The by-product coking industry owes its progress to some of these phases, arising primarily out of man's need for increasing quantities of iron and steel for his peaceful needs, and, sad to say, was also stimulated largely by his requirements in instruments of offence and defence.

Charcoal, the first reducing agent used in the production of iron, was superseded by the carbonaceous residue obtained in a similar manner by the use of coal instead of wood.

Ideas as to the better utilisation of the energy made available by the carbonisation of coal bore fruit, developments in heating systems, such as the introduction of the principle of regeneration, came about, and uses were found for by-products in the expanding chemical industry, so that encouragement was given to the study of the by-product coking process.

In turn, this led to the production of suitable constructional

materials, increase in size of plant, and the introduction of labour-saving machinery. Associated also with this progress was the cleaning of small coal and the utilisation of what, in many instances, had been considered hitherto as waste, or as of too low a grade to be employed in the manufacture of coke.

In more recent times, much study has been given to the question of heat economy with a view to increasing the amount of available gas. With this object in view, in addition to improvements in design of flues, etc., ovens have been constructed so as to be heated by poorer gases such as blast furnace or producer gas, thus liberating a greater part, or the whole, of the richer coal gas.

The obtaining of a true heat balance of the process has been, up to now, a difficult task, and is regarded by some authorities as impracticable. Suffice it to say that of the heat transmitted to the oven—using coal of 30 per cent. volatile matter and containing 3-4 per cent. moisture—67 per cent. is utilised in carbonisation of the charge, being discharged in the hot coke, gases and water, etc., vapours, radiation or other losses, whilst the last-mentioned items, together with chimney loss, makes up the remaining 33 per cent.[1] Although, owing to the intermittent nature of the coking process, it is impossible to reduce completely to zero these losses, much attention has been, and is being, devoted to the problem of heat conservation by the introduction of insulating materials and the speeding up of charging and discharging operations. In view of the claims made by some constructors, it is very desirable that heat measurements be undertaken on modern plants by independent and competent investigators recording all the factors pertaining to the test, but we make the suggestion with diffidence, knowing full well the difficulty of inducing firms to agree to such a trial.

Energy Available from the By-Product Coke Oven

In considering this we have refrained from treating the matter from any but a very general point of view, as any statistical figures necessarily would apply only to the particular coal under discussion, and would be comparative only when carbonising and recovery conditions were identical. The industrial uses of the resultant products of coking, solid, gaseous and liquid, are by far the most important, and will be dealt with in that order.

COKE. As a source of industrial energy coke is one of the most important and valuable fuels.

[1]Porter—Coal Carbonisation.

Coke is primarily manufactured in the coke oven for utilisation as a reducing agent in the blast furnace, and, as such, plays a vital part in the economics of the heavy industries as the source of blast furnace gas.

In ideal circumstances, blast furnaces are to be found working alongside coke ovens on the one hand, and iron and steel works on the other. Such a self-contained works has everything in its favour from the point of view of the complete utilisation of the energy lying latent, both in the coal and the coke, for, in the first instance, the coke oven gas produced during carbonisation can be used in the steel works soaking pits, etc., while the blast furnace gas is absorbed in heating the coke oven flues or in the production of electrical power by the medium of gas engines or boilers and turbo-generators.

The importance of heating coke ovens by blast furnace or other low calorific value gas has just begun to be realised in this country, although since the war a considerable number of installations designed for this purpose have been erected on the Continent. Several are, however, now under construction or projected in Great Britain, and if purchasers were satisfied regarding the cost and efficiency of dust-extraction plants, progress where conditions are favourable, would be rapid.

The utilisation of blast furnace gas for power production by means of gas engines is now common practice; the power, in its turn, being used in driving machinery in the adjacent engineering shops. The largest gas engines in the world (7,000 H.P. each), are to be found at a well-known works in Derbyshire, while at many other centres gas engines are running regularly and satisfactorily on this gas as a fuel.

In many other ways coke plays an important part in the production of energy in industry. Thus, much steam for general use, and also for the driving of turbo-generators for electrical power production, is generated from small coke-breeze and dust, either charged alone or mixed with coal slurry on to a specially constructed boiler furnace. This, in many cases, is the only way of disposing of such low-value products of the coke oven, and is a cheap method of steam and electricity production for consumption on or near the producing plant.

The firing of specially designed boilers with pulverised coke-breeze and dust of a suitable quality, is a development of which more will be heard in the near future.

The carbide, cyanamide and carborundum industries, to mention only a few, depend upon the latent energy stored up in coke, while

vast quantities are absorbed in the production of "blue" water gas. Producer gas, as a rule, is generated from coal, but within recent years the utilisation of coke and coke dust in this connection has made rapid progress, until now producer gas is of special interest to the managers of modern coking plants, fortunately situated geographically for the disposal of their high-value calorific coke oven gas, in so far as they can, by the utilisation of their small breeze and dust in this manner, generate producer gas for heating their ovens and so liberate the whole of the coke oven gas for industrial or domestic purposes. In this connection it is quite possible that, in the near future, a large additional production of coke-breeze and dust may result from the breaking of coke for domestic use, the only economic method of disposal of which is by means of some suggestion such as is offered above.

COKE OVEN GAS. Coke oven gas is a source of energy in industry, the value of which, in this country at any rate, has not yet been fully appreciated.

In Great Britain it is the exception rather than the rule, to find coke-oven plants situated in close proximity to the iron and steel works, which could, of course, absorb the whole of the gas produced.

As this does not obtain, however, in the great majority of cases, the facts must be looked in the face and another outlet found for the valuable gaseous products of the coke ovens.

For years, even before the first rumours of the great Continental coke-oven gas distribution schemes reached us, a few small voices on both the coke-oven and gas-works platforms were endeavouring to preach the gospel of national thrift in gas. Their labours are only just beginning to bear fruit. The value of coke-oven gas for domestic purposes *via* the gas works has been recognised by a number of centres, and the leaven is spreading rapidly. It is in industry, however, that the producer of coke-oven gas sees his market in the future, and it is towards that goal that he is working hand in hand, if possible, with his colleagues in the gas industry. Cheap, clean and easily controlled gas is only on the threshold of its development as an industrial necessity. Town's gas, at the moment, even at its cheapest, is too dear for many industries, but granted the relaxation of certain Home Office regulations, and whole-hearted co-operation between the producers of town's and coke-oven gas, a vast supply of crude oven gas could be placed at the disposal of manufacturers at a figure which would be profitable to all concerned, whilst a great national asset would be brought into being.

It is true that to-day there may not be a vast quantity of coke-oven gas available, but many modern coking plants are either under construction or projected, so that the gas produced will be augmented in the near future.

In the past, coke-oven gas has, in many instances, been blown away into the atmosphere or has been wastefully used under boilers. Certain firms have successfully transformed it into electrical power by means of gas engines or *via* boilers and turbo-generators. Quite astonishing figures, which can, however, be vouched for, have been produced in connection with the former operation, which finally dispose of the suggestion that good results are impossible in gas engines with such a high calorific gas.

Two instances of the cost of production of electricity by means of gas-engine driven generators, are given:—

ACTUAL WORKING COST OF PRODUCTION OF ELECTRICITY FROM SURPLUS COKE-OVEN GAS

Type of gas engine	4-cyl. tandem (National).	Straight 6-cyl. (National).
Age	10 years	2 years
Horse-power...	450	600
Total B.O.T. units generated ...	1,362,430	4,089,940
Direct and maintenance wages ...	0·072	0·020
Maintenance stores, including water, oil, waste, wipers, emery cloth, sundries, etc.	0·041	0·025
Repairs (outside invoices) ...	0·051	0·0015
Depreciation of engine, 7½ per cent.	0·051	0·029
Purifiers, 50 per cent. wages and oxide of iron	0·005	0·0015
Cost of gas at 3½d. per 1,000 cu. ft.	0·105 (*a*)	0·087 (*b*)
Depreciation on gas holder ...	0·007	0·002
Total cost per B.O.T. unit ...	0·332	0·166

(*a*) 30 cu. ft. of gas per B.O.T. unit.
(*b*) 25 cu. ft. of gas per B.O.T. unit.

So far, in this country, coke-oven gas has not been utilised in connection with the various processes for synthetic ammonia production, etc., but with the period of coke-oven reconstruction just commencing, it will be surprising if within the next few years some such developments do not occur.

TAR. Tar in Great Britain is considered too valuable a substance to be used as a fuel in the raw state. As such it has been extensively utilised, particularly in America. Its liquid distillation products in the form of creosote and heavy oils were of welcome use as naval fuel oils during the Great War. Pitch, too, finds a useful if an

apparently diminishing outlet in the manufacture of patent fuel and briquettes, and also in the electro-chemical industries.

BENZOLE. Benzole, in the rectified form, is probably the best motor fuel on the market for the existing types of motor car engine, and it is worthy of note that the first east to west Atlantic flight was accomplished on this fuel.

AMMONIA. Ammonia as a fertiliser and source of plant nitrogen takes its place in the list of valuable sources of energy to be obtained from the by-product coke oven. It played a noteworthy part, together with derivatives of benzene and toluene, in the supply of the high-explosives necessary for the late war, and these compounds naturally have their many peace-time uses. The use of ammonia as a refrigerant is another application. The by-product coking industry now feels the competition of synthetic ammonia, but, in that it renders possible the production of hydrogen either by the coke—water gas method, or from coke-oven gas, the industry will perform a useful rôle. Cheap hydrogen and carbon monoxide will, in years to come, become very important raw materials in the conversion of solid coal and coke into liquid fuels.

Energy for Domestic Purposes

As we have seen, the by-product coking industry was developed primarily in connection with the iron and steel industry, and the use of its products for domestic purposes is another evolutionary stage. The development of central heating, particularly on the Continent of Europe and in the United States, drew attention to the possibilities of *graded* coke-oven coke as suitable fuel for that purpose. In these islands evolution has been slower, yet there is an increasing demand for cut and sized coke-oven coke in the larger cities, influenced by the uniformity of quality as regards ash and moisture due to the methods used in coal preparation and coke production. Arising out of this it has been found practicable to burn certain types of coke-oven coke in ordinary grates, and more successfully so in specially designed grates. This has drawn the attention of the coking industry to the production of a specially suitable domestic fuel. Many competent students of the problem believe that, in the carbonisation of coal to produce suitable domestic fuel, the high-temperature coke oven worked under suitable conditions and, supplied with a suitable coal or blend of coals, will yet play a very important, if not the most important part in attaining the ideal of a smokeless land, for in addition to the solid product, the gaseous and liquid products are materials of known commercial value.

That there is a trend in this direction is seen in the United States, where the modern by-product oven is built with a view to the production of domestic solid and gaseous fuel, and on the Continent where the distribution of coke-oven gas for town's purposes over long distances is an accomplished fact.

Trend of Development

References have been made in preceding paragraphs to the many apparent signs in this country of the commencement of a period of reconstruction in the coking industry. This is not without significance, for it demonstrates the fact that the more progressive of our industrialists realise that the industry has not kept abreast of the times, but was in danger of falling into a state of decay which would inevitably affect, adversely, the whole industrial fabric of the country.

With its rehabilitation, however, the whole picture of the future changes, and already developments, which a few years ago dared not even be dreamt of, are taking shape. Such developments have unquestionably been influenced by the great Continental schemes in Germany, Belgium and Holland, for the perfection of the distribution of coke-oven gas for domestic and industrial purposes. The utilisation of gas per person in these islands far exceeds that of the countries mentioned, but we would not say that it has reached the highest level. It may not be possible, nor indeed advisable, to carry out a gas grid scheme of the same nature as, say, the German one, but, undoubtedly, some modified or localised development of the same or a similar type will have to come about. Industry wants cheap energy in the form of gas, and when one considers how much could be saved nationally by eliminating the transport of raw coal by wiping out the cost of disposal of ash and dirt, by doing away with uneconomical boiler and gas-producing plant, as well as the maintenance and labour costs involved in connection therewith, the case for cheap gas—which means crude coke-oven gas—surely requires no advocate other than common sense.

Again, one hears everywhere the demand for a satisfactory smokeless fuel. To-day gas works, coke ovens, and low-temperature plants are striving after this ideal. It can hardly be said to have been achieved as yet in a form which appeals to the public. To be satisfactory it must be clean, dry, physically strong, comparatively cheap, and finally, and probably most important of all, easily combustible. A great field here lies before the reconstructed coke-oven industry, and, from what one hears, those responsible will not

be slow to seize every opportunity for exploiting to the full the possibilities of a proved system of rational utilisation of coal.

ZUSAMMENFASSUNG

Die Verfasser geben zuerst einen kurzen geschichtlichen Überblick über die Kokerei-Industrie und die Gewinnung von Nebenerzeugnissen; nach einer Schilderung der gegenwärtigen Lage gehen sie über auf den Gang der Entwicklung, der für die nächste Zukunft zu erwarten steht.

Die Energie, die von Koksöfen fur Gewinnung von Nebenerzeugnissen gewonnen werden kann, wird nur von einem ganz allgemeinen Gesichtspunkt aus behandelt, da statistische Angaben nur für die betreffende Kohlenart Gültigkeit hatten und bloss dann von Bedeutung waren, wenn die Vergasungs- und Gewinnungsverhältnisse dieselben waren. Die Verwendungsmöglichkeiten dieser Nebenerzeugnisse in der Industrie werden eingehend behandelt, da sie bei weitem die wichtigste Seite des Problems darstellen.

Die britische Kokerei-Industrie steht vor einer Periode des Wiederaufbaus. Die Industrie braucht billige Kraftquellen, und die Entwicklung der Kokerei-Industrie geht dahin, in dieser Hinsicht bedeutende neue Quellen zu erschliessen.

ECONOMICS OF COKE MANUFACTURE IN THE COKING INDUSTRY

THE JOINT FUEL COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS, THE SOCIETY OF CHEMICAL INDUSTRY, THE COKE-OVEN MANAGERS' ASSOCIATION, AND THE INSTITUTE OF FUEL

M. MACKENZIE

Paper No. G6

CONTENTS

INTRODUCTORY

The close connection between the coking and the coal and iron and steel industries is a commonplace which requires no stressing. On the other hand, any critical appreciation of the economic and technical development of the coking industry in this or any other country which either ignores or does not emphasise sufficiently this interdependence is far from complete.

Again, although generally realised, due weight is seldom given to the fact that technical development is but the handmaiden of economic stress or prosperity. While one naturally expects a progressive technique in any live industry, there is no doubt that the most considerable developments have been made largely as a result of conditions of economic hardship or economic prosperity—a seemingly paradoxical statement.

An excellent illustration of this process is afforded by the evolution of the by-product coking industry from the beginning of the present century or by contemporary developments in Germany and America, inspired as they are in the former country by conditions of stress and hardship, and in the other by prosperity, unparalleled in the history of any country.

Primarily, the coking industry was established to supply an essential raw material for the manufacture of pig-iron, and apart altogether from the ebb and flow of the pig-iron industry, there are indications of appreciable growth during recent years.

In Scotland, for example, metallurgical coke has largely taken the place of the splint coal which, until recent times, was the basic fuel employed in Scottish blast furnaces. There are also indications that an increasing outlet will be found in the field of domestic and general industrial requirements, and any legislation directed towards smoke abatement in the metropolitan and urban areas would give a material impetus to the coking industry and to the carbonising industries generally.

As the pig-iron industry has been and is likely to remain the principal consumer of by-product coke, this potential expansion may to some extent be offset by the considerable advances which have been made in blast furnace technique in the direction of reducing the fuel consumption per ton of pig-iron made, so that any natural expansion in the volume of the pig-iron industry in the next decade may not necessarily involve a corresponding expansion in the coking industry.

Taking everything into consideration, therefore, it would appear that the volume of production in the coking industry should remain fairly stationary over the next few years.

While primarily established to produce an essential raw material for the manufacture of pig-iron, the coking industry has become more and more an outlet for less readily saleable grades of bituminous coals. Researches into the coking possibilities of coals of lower coking indexes by admixture with highly coking coals and in the de-sulphurisation of coking slacks generally, if they do not enlarge the sources of supply may make some compensation, at all events, for the gradual exhaustion of coals of good coking quality.

The by-product coke-oven was designed not only to recover the gaseous and liquid products of carbonisation, which in the beehive oven, with isolated exceptions, were either allowed to go to atmosphere or used for heating auxiliary plant, such as brick and lime kilns, but also as a user of lower quality slacks and the residual fines of coal washeries.

There are many seams which could be worked by machine-mining methods which cannot to-day be worked economically by hand. As the field of machine-mining widens, a lesser proportion of small

but a greater proportion of fine coals may be produced. The excess, if any, is likely to be absorbed as smokeless fuel, as hydrogenation processes are perfected and commercialised.

Bearing in mind, therefore, the gradual exhaustion of highly coking coals, the possibilities of utilising inferior coals, the *sequelæ* of machine-mining and the invention and perfection of new carbonising processes, the general conclusion so far as the immediate future is concerned, would appear to be that we are not likely to experience a reduction in the price of the basic raw material of the coking industry. What we can look to the future for, however, are coals—and the writer is speaking now of that section of the industry outside of Durham—which by careful selection and treatment are capable of conversion into a product lower in ash and sulphur content, and, consequently, more valuable than the coke of to-day.

EXTENT OF THE INDUSTRY

There are some 9,500 by-product ovens of various types in England, Wales and Scotland, comprised in 154 plants, employing in round figures 15,000 workpeople, including by-product labour.

In addition, there are about 2,500 beehive ovens in the country, but the figure grows less each year and has come down from over 13,000 in 1913 to 2,229 *in use* in 1925.

The following figures indicate the extent of the coking and by-product industry expressed in terms of its consumption of coal and production and disposal of coke, as shown by the official figures of the Board of Trade for the years ended December 31, 1924 and 1925:—

AT COKING AND BY-PRODUCT PLANTS—ENGLAND AND WALES AND SCOTLAND

Year.	Total coal carbonised.	Total coke produced	Coke consumed : inland.	Coke exported
	Tons	Tons	Tons	Tons
1924	18,862,492	12,753,358	10,903,667	1,849,691
1925	16,393,867	11,008,686	9,755,950	1,252,736

One ton = 2,240 lb.

In 1923 the iron and steel industries consumed 8,645,700 tons of metallurgical coke, 8,744,800 tons in 1924 and 7,465,600 tons in 1925.

The total capacity of all by-product ovens in England, Wales and Scotland is 21,000,000 tons of coal per annum, and the

production of coke would appear to be adequate for the present actual and potential requirements of the iron and steel industries, and still leave a surplus for export and other markets.

Economic Position

The present economic position of the coking industry in this country can, perhaps, be best explained and analysed by a comparison between the costs and results of operation over the past twenty-seven years, with particular reference to the three outstanding types of coke-ovens which have, in turn, been employed during that period—the beehive, the by-product waste heat and the modern by-product regenerative oven.

At this stage it should be emphasised that the data given are largely parochial and not intended to be representative of national practice. Whatever merit they may contain will consist in the fact that due care has been taken to compare like with like—coking units of moderate and similar size being the basis of comparison throughout.

Capital Costs. The following table sets out the comparative capital cost per oven and per ton of daily coal throughput for four types of coke-oven—the beehive, the by-product waste heat, the by-product regenerative and its present-day successor:—

CAPITAL COSTS OF COKE OVEN PLANTS

Period.	Type.	Per Oven: Cost	Per Oven: Capacity	Per Oven: Daily throughput of coal.	Cost per ton of coal carbonised per day.
		£	tons	tons	£
1901/1903	Beehive	120	4	2	60
1904/1914	By-product waste heat	1,000	9	6	166
1919/1921	Do. regenerative ...	3,400	12	9·4	360
Present-day	Do. do.	6,800	15	20	340

In examining the figures in the above table, it should be remembered that they are subject to variations according to the district, class of coal carbonised and whether the coal is dry or washed. The period 1919/1921 may be regarded as the time when prices were most inflated, and the cost per oven of £3,400 as the peak figure for that period.

As between the original beehive oven and its successors no comparison is intended to be drawn, for the capital cost of

by-product ovens necessarily includes the cost of the by-product recovery plant itself, but what is interesting and apparent in the figures relating to the by-product types (apart from the marked increase in the cost of building and constructional material) is the extent to which the change in the fabric brought about by the demand for more output per unit, and the addition of such ancillaries as modern coal and coke handling appliances, have materially added to the capital cost per oven.

Costs of Operation. The all-in conversion costs per ton of 2,240 lb. of coke, including by-products, roughly corresponding to the periods shown in the table of capital costs, are given below. In these costs, steam, whether used for process or mechanical work, is included under the heading of "Materials" and the cost of electrical power under "General charges." Every effort has been made to reduce the comparison to a common denominator, and the apparent discrepancy between the figures for depreciation in this table and the figures calculated at a uniform rate on the figures of capital cost given above is due to the fact that these conversion costs relate to actual operating conditions and that consideration has been given to such circumstances as the respective ages of the ovens and the probable duration of their useful life.

COMPARATIVE CONVERSION COSTS

Costs.	Beehive 1901–1903.		By-product ovens. Waste heat 1913		Waste heat 1927.		Regenerative 1928.	
	s.	d.	s.	d.	s.	d.	s.	d.
Wages	2	10·5	2	8·4	3	9·0	1	9·5
Materials		0·1	1	9·5	2	6·5	2	3·5
Repairs		6·8	1	2·4	2	7·6	1	1·0
General charges ...		5·9		4·7	1	0·0	1	0·0
Depreciation ...		1·9		11·2		9·5	1	6·0
Total ...	4	1·2	7	0·2	10	8·6	7	8·0

In the modern regenerative type there is normally produced about seventy therms per ton of coal of high-calorific gas, of which a portion or the whole may be available for other purposes, depending on whether the ovens are fired with straight coke-oven gas, blast-furnace gas, producer gas, or a mixture of any of these gases. The conversion cost of this type may, therefore, be appreciably reduced where arrangements can be made for the

commercial disposal of such available gas and its replacement on the coke-oven plant by lean gas or less valuable fuel.

Probably the most interesting feature of these costs is the very considerable reduction which has taken place in the labour cost per ton of coke produced, and in order that these may be compared in detail they are set out below :—

LABOUR COST PER TON (2,240 lb.) OF COKE

Category.	Waste heat 1927.	Modern Regenerative 1928.
	s. d.	s. d.
Coal handling (including drying, crushing and blending)	7·5	1·5
General foremen	1·3	1·3
Ovens	1 7 0	8·0
Coke handling	1·5	0·8
By-product plant	4·5	4·7
General labour (including mechanical and electrical) ...	11·2	5·2
	3 9·0	1 9·5

In the tables of comparative conversion and labour costs the "waste heat" figures relate to the costs of operation in 1913 *and* 1927 *respectively on a waste heat plant erected in* 1905.

A considerable field of enquiry presents itself in the detailed comparison of these labour and maintenance costs—a field which it is not the present writer's intention to enter upon, but rather to suggest as a fruitful one for closer investigation by operators and constructors alike.

With the advent of the modern oven of relatively short coking time, new departures in operating practice become possible. Documented experience would be valuable on such questions as the relative merits of operating on a twelve-hour carbonising period and the practicability of working two eight-hour shifts as compared with longer carbonising periods and the three-shift system.

It is generally admitted that the installation of mechanical appliances depends largely for its success on the capacity of the coking plant. Modern coke-quenching and handling appliances, for example, may be a profitable investment on plants of so-called economic size, namely, those plants carbonising upwards of 1,000 tons of coal per day. It is conceivable, however, that they may be successful on plants of lesser capacity.

Comparisons might also be made on such minutiæ of operating and maintenance experience as self-sealing and non-sealing oven doors, and band conveyors versus elevators for coal handling. Any or all of these major or minor questions, in connection with which there is to-day considerable difference of opinion, would well repay detailed examination by technicians from the point of view of costs of operation and maintenance in their relation to capital cost of installation.

Results of Operation. In examining the results of operation during the period under review, the writer would at the outset enter a plea for greater uniformity in arriving at such results. Yields of products are variously determined per ton of wet coal, dry coal, and per ton of commercially disposed coke, including breeze, and per ton of dry furnace coke.

Custom in the past has established an ascertainment of the yields calculated per ton of dry coal carbonised, and from the technical point of view much can be said for this practice. On the other hand, where the staple product is and is likely to remain furnace coke, it would appear that if costs and results of operation were expressed per ton of furnace coke, comparisons could be made which would not only act as a healthy incentive to those engaged in the industry but also go a long way towards making feasible the collection of data for the whole industry. Such data would serve as a basis of comparison with conditions in other countries and with other processes of carbonisation, such as the low temperature process.

The table below illustrates the trend of the selling prices of the various primary products as compared with the price of coking slack. The prices prevailing in the year 1913 have been used as the basis of comparison (price index=100).

AVERAGE SELLING PRICES

Price Index for year 1913= 100

Period.	Slack	Coke.	Tar.	Sulphate of ammonia.	Benzol.
1901–03	56	90	—	—	—
1904–06	66	76	67	88	—
1907–09	79	81	59	84	—
1910–12	79	77	78	89	90
1913	10	100	100	100	100
1914–16	108	110	80	102	128
1917–19	187	192	92	117	306
1920–22	242	255	315	140	620
1923–25	145	127	245	86	371
1927	150	122	248	62	387

Broadly speaking, these figures illustrate the marked variation which has occurred in the price of coking coal, and, in the years since the "boom" period of 1919-1921, the reduction which has taken place in the value of coke, consequent on the reduced demand from the principal consuming industries, together with the reduction in the value of sulphate of ammonia which has followed on the very considerable expansion of the synthetic ammonia industry.

The trend of the prices of coke between the years 1903 and 1913 shows the initial recession when by-product coke first replaced beehive coke and the gradual establishment of the former at the end of ten years as a product for blast furnace purposes, if not superior, at all events of equal value to beehive coke.

Towards the end of 1927 and during the present year there has been an even more pronounced reduction in the price of coke, whose price index to-day has fallen to 90, while no corresponding alteration has been experienced in the value of coking slack to offset this void in the revenues of coking plants.

Present-Day Issues

These present conditions of economic stress have brought to the fore in this country two questions which have for many years been exercising the minds of those who are most intimately connected with this industry—the centralisation of small units and the bulk supply of coke-oven gas.

Unification. The coke-oven industry is an integral part of our iron and steel industries, and any concentration of coking units which does not form part of a larger scheme of unification and rationalisation of our principal iron and steel producing plants would possibly defeat its own object, for whatever might be gained in economy of production might in a large measure be lost by increased freight or transport costs on both the raw material and the manufactured products of the industry.

Mr. Ernest Bury, writing recently on this question of unification and making particular comparison of conditions in the coking industry in this country and in America and Germany, stated that the large plants in America and Germany were, in most cases, put down at iron and steel works of enormous capacity, where there was a use for the coke and gas produced from the unified coking plants. There were no such unified blast furnaces and steel plants in Great Britain. He had lately returned from a visit

to the Ruhr steelworks, where five units produce the equivalent of 60 per cent. of the total steel made in Great Britain. At the Hamborn Works (Vereinigte Stahlwerke) 170,000 tons of ingots were produced per month, equal to 136,000 tons of finished steel, that is 1,632,000 tons per annum. The smallest of the works visited—the Phœnix—produced 80,000 tons of finished steel per month. The coal carbonised at Hamborn was approximately 4,500 tons per day, that is 31,500 tons per week, the whole of the surplus gas from which was used in the manufacture of finished steel, for town's use, and the operation of the company's colliery. We had no such concentrated user of coke and coke-oven gas in British steel works. An average sized British steel unit would produce approximately 3,000 tons of finished steel per week, with coal carbonised equivalent to 6,000 to 9,000 tons, according to economy in fuel practice.

The re-grouping of British iron and steel plants would, therefore, seem to be a condition precedent to a concentration of coking units. When it is remembered that the present building costs for steel works are approximately £20 per ton of steel produced per annum, as compared with a figure of from £8 to £10 per ton in the years prior to 1914, it will readily be realised that a very large capital expenditure is involved if we are to bring about in this country a concentration similar to that effected by the Vereinigte-Stahlwerke or the United States Steel Corporation.

Large-sized coke-oven plants are in existence at German collieries. In such cases there is no user for the gas, and Ruhr colliery proprietors are now seeking to sell such gas to all parts of Germany. Most German steelworks possess their own coke-ovens, and there is, therefore, no gas outlet for the ovens at the collieries in this direction. Further, the coke produced at the collieries is to a large extent debarred from absorption by German steelworks, and the colliery coke-ovens have to seek outlet in other directions.

The general conclusion to be drawn, therefore, would appear to be that unification of coking units on the grand scale is feasible only when a user can be found for the greater part or all of the plant's output in close proximity to the plant itself. On the other hand, there is no doubt that considerable saving might be effected by the concentration of relatively small groups of small plants to form units carbonising upwards of 1,000 tons of coal per day, provided that the following conditions were satisfied :—

1. The plants to be replaced were nearing the end of their useful life, and no great loss of capital would be experienced in their extinction;
2. The transport charges on the raw material and products of the combined plant compared favourably with the aggregate of the individual freight costs of the smaller units; and
3. A use could be found in close proximity to the new plant for its various products, including coke-oven gas.

Bulk Supply of Coke-oven Gas. In its particular application of supplies to gas undertakings this subject has, for a variety of reasons, proved highly controversial in recent times. Whether it is or is not in the national interest is a question on which there is a divergence of opinion. There are, however, certain fundamentals which, in the opinion of the writer, do not always receive the prominence they deserve.

Firstly, apart from such refinements as the utilisation of the sensible heat of the coke as it leaves the oven, coke-oven plants of moderate size are thermally self-contained units. Or to modify that statement slightly and so satisfy the precisian, they are, as a rule, connected with other undertakings, collieries or steel plants which readily absorb whatever small surplus of gas there may be available, either for steam raising, power generation, heating soaking pits, billet furnaces, or the like. It follows that there is, broadly speaking, no such thing as gas, surplus in the sense that it is not consumable at or near the point of production; in other words, there is no waste gas, and coke-oven gas is not a *waste* product.

While in the sense referred to there is no surplus gas, as such, there is, and will be available for purposes more economically suitable than those described above, an increasingly larger quantity of gas which can and should be replaced by fuels less costly and equally effective for what might be termed the cruder or more wholesale uses which coke-oven gas has served in the past. We are, therefore, dealing with a question of margins rather than that of absolute values—the margin between the value of coke-oven gas to the coke-oven operator in terms of raw fuel, such as steam coal or some other replacing fuel, such as blast-furnace gas and its value to the statutory producer of gas for domestic and allied purposes. Both these values are capable of exact determination.

Secondly, assuming (*a*) that the statutory producer or gasworks undertaking has been given the adequate safeguards to which he is unquestionably entitled, (*b*) that there is, for the sake of argument, in this country a source of demand, figuratively speaking, on the doorstep of the principal centres of the coking industry, sufficient to absorb the available quantities of coke-oven gas without distributing this gas to the urban areas remote from the industrial North, then it would appear that this question is one for co-operation, to their mutual advantage, between the interested parties on the spot, and in this connection it is pleasant to record that there is a growing recognition of this spirit of co-operation between the two carbonising industries.

Conclusion

A few words here as to the possible economic future of this industry may not be inappropriate. The stress, which in Germany seven or eight years ago gave the requisite impetus to the radical rehabilitation of their iron and steel industries, is to-day being very keenly felt in Great Britain, and indications are forthcoming that similar reactions may ensue. Associated with this impetus, the more rational attitude of all political parties towards industry in general and the basic industries in particular, together with the growing co-operation between the two great carbonising industries, should go a very long way towards the re-establishment of the coking industry of this country on an economic basis, which would bring in its train undoubted benefits and material assistance to the industries with which it is allied and of which it forms a part.

ZUSAMMENFASSUNG

Die Verkokungsindustrie bildet einen wesentlichen Bestandteil der Stahl- und Eisenindustrie, und ihr Gedeihen hängt grossenteils von deren Wohlergehen ab.

Die schrittweise Ausdehnung der Verkokungsindustrie in Grossbritannien dürfte in nächster Zeit durch den Fortschritt der Hochofentechnik einigermassen ausgeglichen werden, und die zunehmende Erschöpfung der Kohlen mit guten Verkokungseigenschaften dürfte durch Erforschung der Möglichkeit, bisher als nicht-kokende Kohlen betrachtete Kohlen zu verkoken, einen gewissen Ersatz finden. Der allgemeine Schluss wurde demnach darauf hinauslaufen, dass sowohl der Umfang der Erzeugung wie der Preis der Ausgangsmaterialien dieser Industrie in nächster Zeit wahrscheinlich unverändert bleiben werden.

Nach einigen Angaben über die Verbreitung dieser Industrie vergleicht der Verfasser die nachfolgenden vier Typen in Bezug auf Einrichtungs- und Betriebskosten: den Beehive-Ofen, den Nebenprodukt-Ofen vor 1914 und nach 1919, und dessen heutigen Nachkömmling für grosse Ausbeute.

Das kennzeichnende Merkmal der Anlagekosten eines modernen Ofens ist die Steigerung der Kapitalkosten pro Tonne vergaster Kohle, die auf die Vergrösserung der Öfen und auf die Verwendung von Koks- und Kohle-Förderapparaten zurückzuführen ist, wodurch allerdings eine grosse Ersparnis an Arbeitslöhnen pro Tonne Koks erzielt wird.

Es wird auch auf die Notwendigkeit hingewiesen, eine grössere Einheitlichkeit bei der Feststellung der Betriebsergebnisse obwalten zu lassen, und es wird angeregt, die englische Tonne Hochofenkoks als Grundlage zur Berechnung sowohl der Kosten wie auch der Ausbeute einzuführen. Eine solche Einheitlichkeit würde den Austausch von Nachrichten sowohl international als auch zwischen Einzelnen sehr erleichtern.

Beim Behandeln der in der Industrie herrschenden Preise wird aufmerksam gemacht auf die grosse Preissteigerung für Feinkohle seit Beginn des Jahrhunderts und auf den ausgesprochenen Rückgang des Kokspreises seit der zweiten Hälfte des Jahres 1927; der Kokspreis steht jetzt nämlich auf derselben Höhe wie vor etwa 25 Jahren.

Zum Schluss wird noch auf zwei Fragen hingewiesen, die Besitzer und Techniker beschäftigen: Vereinheitlichung und Grossversorgung mit Koksofengas. Nach Ansicht des Verfassers ist eine grosszügige Vereinheitlichung in Grossbritannien nicht mehr durchführbar, es liesse sich aber durch Erfüllung gewisser Vorbedingungen immerhin noch eine gewisse Konzentration erzielen. In Bezug auf die Grossversorgung mit Koksofengas sollte eben erkannt werden, dass Koksofengas kein Abfallprodukt ist und dass diese, wie so manche andere die Gemüter der Industrie bewegende Frage schliesslich doch nur durch die Zusammenarbeit aller beteiligten Kreise gelöst werden wird.

COKE QUENCHING AND COOLING

THE JOINT FUEL COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS, THE SOCIETY OF CHEMICAL INDUSTRY, THE COKE-OVEN MANAGERS' ASSOCIATION AND THE INSTITUTE OF FUEL

W. COLQUHOUN

Paper No. G7

CONTENTS

The constitution of good blast-furnace coke is a subject of discussion as old as the iron industry itself. It is brought into new prominence in the coke oven industry as well as in the gas industry by the realisation that coal of good quality is no longer cheap and abundant. Therefore a better knowledge and control of the production of the coke derived from it has become an economic necessity which has given birth to great activity in investigating all the means of the efficient and economic manufacture and use of coke.

Among the subjects dealt with at this conference the present communication is concerned only with the subject of quenching and cooling coke. Let us consider first the method of quenching with water, in common use since earliest times.

QUENCHING WITH WATER

Coke Wharf. A flat wharf has been greatly used, and is still to be found in many of the early plants in use in England and on the Continent. When the coke is passing out of the oven the mass is pulled down right and left with hooks and quenched with the hose. Sufficient time is allowed for the coke to steam off and cool, before being loaded into wagons. In later plants the wharf is

inclined at the angle at which the coke will slide of its own accord. In the instance of the inclined wharf, as shown in Fig. 1, the quenching hood, the invention of J. H. Darby, which is applicable only to an inclined wharf, may be introduced. This is a coke

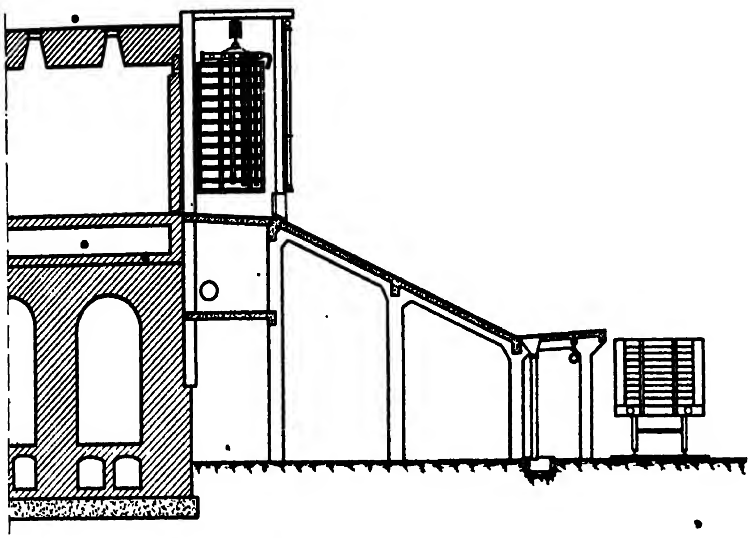

Fig. 1. Inclined coke wharf with suspended Darby quencher.

guide built of perforated pipes, connected by a hose to water at a pressure of about 50 to 70 lb. per sq. in. The pipes are so arranged as to deliver the bulk of the water into the heart of the coke batch, just as it breaks on the top edge of the wharf. The coke is then forked directly into wagons, the fork being in itself quite an efficient screen. The degree of inclination is arranged to suit the character of the coke and the material of which the slope is constructed. For example, on a plated slope, the best Barnsley or South Wales cokes may have wharves inclined at 23½° with the horizontal, while a soft coke may require up to 28° of inclination. The inclination should be no more than is necessary for the coke to slide, because the fall of the coke, as it is pushed out of the oven, is already sufficiently severe, and is exaggerated by increasing the inclination. Again, if the inclined slope is not long enough, or not steep enough, the coke will not spread thinly and evenly over the surface on being pushed, but will build up into heaps, when it is apt to fire again. Provision has, therefore, to be made at the foot of the slope for a supplementary water main

and hose connections, for quenching hot spots. Spot quenching is the prime cause of irregular and excessive water in the coke.

With the idea of ensuring a more complete quench, the Darby hood is often mounted upon a travelling carriage; the inclination of the wharf begins on the floor of the quencher itself in order that the batch may break while the coke is still within range of the water jets (Fig. 2). The main stream of water is directed into the heart of this break. The coke on the wharf is released at the foot of the inclination by a line of swing gates, and carried away to the mechanical screens by means of a con-

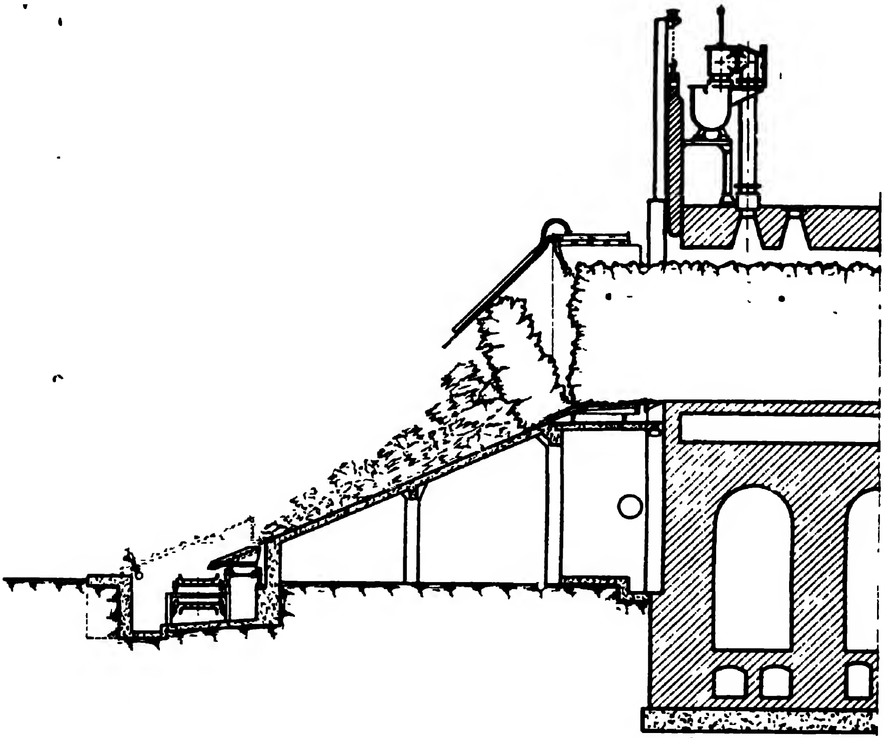

Fig. 2. Inclined coke wharf with Darby quencher mounted on a car

veyor. The gap between the edge of the wharf and the conveyor is spanned by a light apron-car running on a rail track. When quenching, this car is pushed out of the way (its axles run on ball-bearings), the water and coke breeze falls into the conveyor gully, and thus the conveyor is protected. The apron-car is brought into use only to bridge the gap between the wharf and the conveyor when loading coke.

Another method of linking up a quenching wharf to a mechanical screening station is shown in Fig. 3, the conveyor in this instance

being a Robins' belt. It will be observed that, to avoid providing feeder rolls along the whole length of the wharf there is a travelling car, electrically operated, with a short length of feeder rolls which take the coke off the edge of the wharf and put it on the belt. The rush of quenching water and breeze is avoided by moving the car to one side.

Fig. 3. Inclined wharf transfer car with roll feeders, and Robins' belt conveyor.

The speed at which the coke is pushed has to be slowed down[1] in all cases in which a Darby quencher is in use and, even when this is done, a supplementary hose is necessary for spot quenching. The pushing speed is usually about 10 ft. per minute.

The cost of a plated wharf for sixty large ovens, excluding gates and conveyor, is about £6,000.

It has been claimed that quenching wharves such as these described give a certain amount of stocking room to carry over

[1] The thermal loss due to keeping the oven door open too long is investigated by R. W. Davies, "Coke-oven Managers' Year Book," 1926-7, pp. 277-278.

interruptions to works operation, due to plant breakdowns or wagon traffic delays. The capital cost is relatively low and they serve well enough so long as small individual installations are built and operated on what may be termed firebrick conditions as opposed to silica.

For a modern silica battery of high capacity and intensive output, however, the quenching wharves described are unsuitable, for the following reasons. The coke cannot be effectively quenched without running the danger of damaging the silica walls by water; the weight and length of the coke batch makes the length of the slope structurally expensive; the time interval between discharges has become too short, and there is too much interference with the other necessary operations.

Coke Car. The coke may be pushed out on to a coke car with an inclined floor. This type of car is 50 to 60 ft. long, and 12 to 14 ft. wide on the slope, and it is preferably built in two parts, each mounted upon two standard railway axles and wheels. The coke is pushed out through a Darby quencher while the car is moved slowly, so as to spread the coke thinly and evenly over the whole surface of the floor, with the object that the surplus water may be steamed off by means of the hot coke, the interior of which is still red hot long after the surface is quenched. The coke car is not to be confused with the quencher car used for remote quenching, for the two are designed on quite different principles—the first to expose a maximum and the latter a minimum of surface of glowing coke.

The coke car has had a considerable vogue in this country. By means of an electric motor or rope haulage it may be taken at once up an incline to the screens. The first cost is, therefore, not heavy. An installation embracing coke cars and an electric hoist, as an alternative to an incline, is shown in Fig. 4, in which the car is lifted to a screen house interposed between two batteries. A Darby quencher and coke car may be seen and, in the background, an empty car is standing on the hoist platform. The cars are moved by electric locomotives, remote-controlled by an operator in the high cabin behind the hoist, who works also the hoist. The controls are all interlocked in proper sequence.

Other Methods of Quenching with Water. In England and on the Continent there have been designed a large number of quenching machines, which travel along the battery and handle the coke

as it is pushed from successive ovens. Some of these machines have water sprays, and some have tanks in which the coke is totally immersed. The inventor has been very busy in this direc-

Fig. 4. Coke car and hoist.

tion, and many of the ideas have died in their infancy or have not stood the test of time. They are too many in number to review in the space available.

The most promising of these is the *Greensmith* machine, which consists of a receiving tank and a draining table spanning the wharf and coke wagons, the whole mounted on an underframe and wheels to travel on a rail-track along the discharge side of the battery of ovens. A manganese steel creeper sweeps the inside of the tank and carries the coke out of the water on to the drying and cooling table and, after a suitable interval for drying, into the wagons. The coke is immersed one minute and a period of thirty minutes is allowed for cooling. The machine is therefore locked up during the cooling interval, but arrangements could no doubt be made to discharge the coke on to a stationary wharf and so release the machine. The machines at the Wharncliffe Silkstone Collieries (to the management of which the writer is indebted for these figures) have handled 209,000 tons of coke at a labour cost of 2·602d. per ton (2,240 lb.). Maintenance labour costs 0·611d ; material 0·948d.; total 1.559d. per ton (2,240 lb.) of coke loaded; moisture in the quenched coke is stated at 2 to 2½ per cent.

Remote Quenching. In the practice of this method, used at most plants in America and now coming into vogue in some installations in England and on the Continent, the coke is pushed into a quenching car at some speed ("pusher" in and out in 70 seconds), and taken quickly to the quenching station by means of an electric locomotive. The station is a tower in which is grouped the spray pipes, concentrating on the contents of the car, while the tower forms a chimney to carry away the clouds of steam. A solenoid-operated main water valve is opened and closed through the contactor rails of the locomotive, as it moves in and out of the quenching position, and the surplus water is settled in breeze tanks and returned into circulation. The practice for a normal coke is to use 600 gallons of water per ton (2,240 lb.) of coke over a period of 50 or 60 seconds. For a minute or so the coke and car is allowed to stand to drain off surplus water, and the locomotive then takes the car to the wharf, where the coke is allowed to slide off and stand until cool. To protect the Robins' belt, experience has shown that there should be a supplementary quenching main with 1½-in. hand-hoses to quench any hot spots that may develop on the wharf. The accompanying Fig. 5 is a section through the ovens and the wharf, showing the coke guide, quencher car, finger gates, feeder rolls, and Robins' conveyor. In the background is the quencher tower.

The cost of such an equipment (quencher car, electric locomotive and contractor rails, quenching tower, water tank, pipes and valves) would be about £10,000.

When dealing with constant weights of coke and water, the water in the coke may be maintained constant and, except in the case of very soft cokes, need not exceed 2 per cent. The equip-

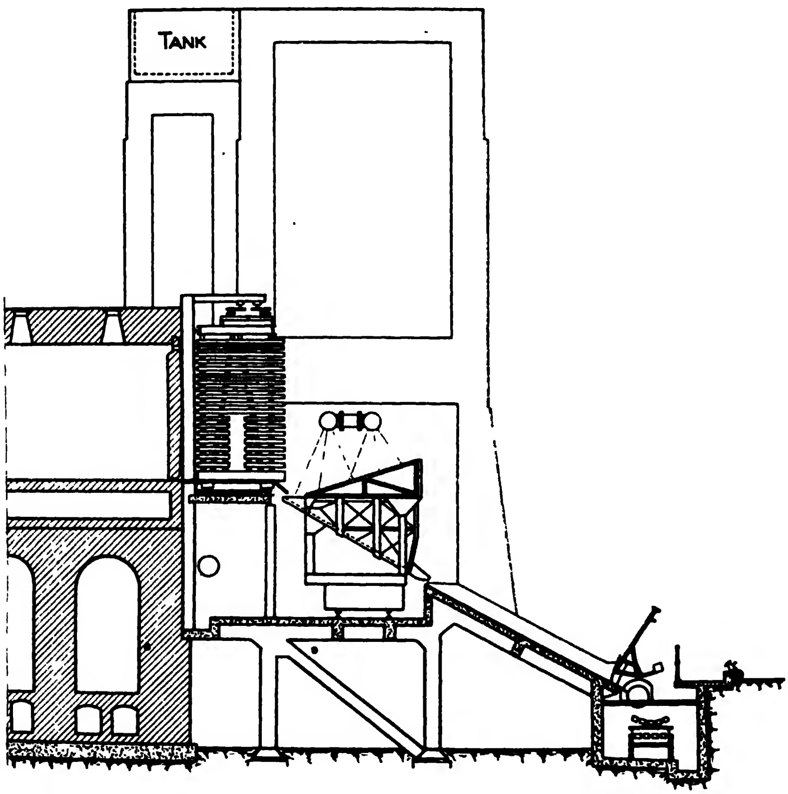

Fig. 5. Section through ovens and coke wharf, showing roll feeders, conveyor and, in the background, coke quenching tower.

ment illustrated will easily handle 1,000 tons (of 2,240 lb.) of coke per day, or more, and only two men per shift are required, from the time the coke leaves the coke guide until it is screened and delivered into the several wagons—one man operating the locomotive and wharf gates, the other attending to the screens and loading the wagons.[2]

[2] Mr. G. A. Hebden, general manager of the South Yorkshire Chemical Works, permits the writer to make this statement

Water Quenching in the Gas Industry. In a gasworks the coke is usually quenched as it drops into the conveyor passing along the retort house, or sprayed as it is delivered from a transporter. Many of the arrangements admittedly fail to maintain the low and constant coke moisture that is desired. The results obtained depend very much upon the caking quality of the coals used and, if mixed, upon the means provided for the preparation of the mixture. The intermittent vertical type of retort lends itself very well to some of the methods already described, and some such methods have been applied. For example, at Ramsgate the Woodall-Duckham intermittent retorts discharge into skips which pass underneath the retorts, which are then taken to be sprayed with a definite quantity of water under a tower designed to enclose the clouds of steam.[8]

It would appear that the idea of quenching with a measured volume of water is not itself complete unless it is followed up by spreading the coke on a cooling wharf. It may be quenched outright, but would then be too high in moisture. The coke is red hot internally for a time, and when it is allowed to lie thinly, the wet surfaces of the pieces are dried off and air-cooled. Variations in coke quality are very wide, which involves wide variations in the time during which water is sprayed, as well as the time for cooling; the proper treatment has to be ascertained by practice in each case.

The continuous vertical retort solves the problem of quenching in a most attractive manner. The heat of the coke is recovered and the coke itself is delivered dry. Without doubt that system of carbonisation has been a principal agent in promoting the improved standard of gasworks coke now so constantly aimed at.

GENERAL REMARKS ON MOISTURE IN COKE

All technical opinion unites in the declaration that there should be a minimum amount of moisture in coke. Such water has to be evaporated in the blast furnace, or wherever it is used, and it absorbs heat to do so. The steam made and carried away in blast furnace gases is not only of no value, but it adds very much to

[8] "Intermittent Vertical Chambers," by R. H. Ruthven, Carbonisation Conference at Birmingham, February 1928. *Gas Journal*, February 14, and *Supplement*, March 7; also "Vertical Intermittent Chambers," N. J. Bowater; *Journ. Institute of Fuel*, Vol. 1, No. 3, p. 237.

the work to be done in cooling and drying the gas. The blast-furnace man does not want to buy extra coke to drive off this water—he prefers to buy coke, not water.

Many coke makers are able to guarantee a low percentage of moisture, but many blast-furnacemen claim that it is difficult to obtain by-product coke with less than 5 to 8 per cent. of moisture. The working of British blast furnaces was investigated by F. Clements, of Parkgate, in a classic paper[4] which shows that the coke used ranged from 4 to 8.5 per cent., and averaged 6.43 per cent. Only one-third of the furnaces examined were supplied with coke that had 5 per cent. or less of moisture

The moisture content of quenched coke depends largely upon the nature of the coke itself, and there are many gradations from good to bad. Blast furnace and foundry cokes are not always as good as the best cokes from South Wales, Barnsley district, or Durham. Much of it is physically poor and absorbs water readily; it is quenched by old methods; it is shovelled into wagons along with much of the wet breeze that adheres to its surfaces; on loading into wagons it breaks along its fissures and exposes hot surfaces that demand spot quenching, and, being small in size, a proportionately large surface presents itself for absorbing water. A coke with these defects in varying degree arrives at the furnaces in a very bad condition. The variations in coke moisture are wide, and the sampling is not always properly understood and controlled. W. H. George[5] says that the percentage of moisture in small coke may be from two to eight times that in the large, and in large lumps the outer layers may contain as much as ten times more than the inner portion of the lump.

The developments referred to in the previous pages show that it is the constant aim of the coke-maker to find improved methods of keeping the moisture low and regular. Clements' data included several of the best of our English cokes, which quench easily with 2 per cent. of moisture, but in spite of this the average was, as already stated, 6.43 per cent. Probably many cokes of inferior physical structure have an average higher than this. But if we limit our statement to the above-mentioned average, we must note

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[4] "British Blast Furnace Practice." *Proc. I. and S. Inst.*, 1920. Vol. 1, pp. 125-148.

[5] "Moisture in Blast Furnace Coke." W. H. George. *Journ. Soc. Chem. Ind.*, 1919, Vol. 38, pp. 394-396.

that, in a furnace making 150 tons of iron per day and using 28 cwt. of coke per ton of iron, the coke containing 6.43 per cent. of moisture, there will be charged along with the coke 13½ tons of water per day. The influence that this may have upon the economy and efficiency of iron-making has not yet been fully examined, nor have individual experiences been co-ordinated.

E. Harrison[6] says that the loss of heat energy from high moisture, while considerable, is rendered worse by the necessity of frequent alterations to the furnace burden, due to variations in the quantity of moisture. It is not easy to assess the cost of having to work with high and variable moistures, although Harrison does attempt to do so. Again, to obtain the full heating value in the use of the blast-furnace gas made, the gas must be freed from moisture by cooling with water, thus adding to the work to be done in the gas cleaning and cooling plant. But while the advantage of dry coke from a thermal point of view, and the saving of the heat expended in evaporating water, are very obvious economies, there are so many variables in blast-furnace operation that the economy cannot be easily demonstrated. According to Cantieny,[7] practical experience in foundry work has shown that if the coke is by any chance particularly dry, the cupola works more quickly and a greater rate of production is possible, whilst the production is notably diminished when the coke is unduly wet. Again, when using gasworks coke for heating and domestic purposes, the economy of dry-cooled coke may be demonstrated. But the operating conditions in a blast furnace are such that the economy of dry-cooled coke cannot be demonstrated in simple terms. Owing to the inevitable intervention of one or more of the many variables that interfere with the conclusions, even a trial run of a blast furnace for comparative purposes, using water-quenched and dry-cooled cokes alternately, does not, for these reasons, conclusively show the advantage and economy that dry cooling of coke is known to yield.

At Witkowitz there is installed a plant to cool 750 (metric) tons of coke per 24 hours, which has been in operation for one-and-a-half years. The management are satisfied that the dry coke has reduced the coke consumption, but they have not yet enough dry

[6] "Modern Methods of Coke Quenching." E. Harrison, of Ackla[illegible] Ironworks. Paper presented at a meeting of the Coke-Ove[illegible] Managers' Association (see *Gas World*, Coking Section, May 1925

[7] G. Cantieny, in *Glückauf*, 1923, November 14 and 15.

coke to supply 100 per cent. to the furnace, and are, therefore, unable to be precise as to the consumption. On the other hand, they have remarked upon the advantage they enjoy of having a coke that is constant in water, and will, therefore, be constant in its carbon content and, incidentally, after passing through the container, the coke delivered to the furnace is found to be relatively uniform in size. For these reasons, they find the coke consumption to be constant and the operation of the furnace regular.

There is another large installation which, in the constructors' opinion, has effected a substantial economy in the coke consumption at the furnaces, quite apart from the admitted value of the steam. The engineers of the company for whom this installation was built consider, however, that the reduction obtained in coke consumption is partly attributable to new measures of control now practised in charging the furnaces; the uniformity in moisture of the dry-cooled coke, and its freedom from breeze, account in a large measure for the improved operation of the furnaces.

DRY COOLING

The Sulzer Apparatus. The dry-cooling process, of which these instances are given, was introduced by Messrs. Sulzer Brothers. The apparatus consists of a container for hot coke and, alongside it, a boiler, through each of which in succession a current of inert gases is continuously maintained by means of a fan. These gases are delivered into the lower part of the container and travel to the top where the coke is hottest, and thence to a steam superheater and boiler. The gases, now at their coolest, are again re-circulated and so on continuously. The container is maintained practically full by adding new charges of hot coke and by drawing cooled coke periodically from the bottom. During these additions and withdrawals the coke inlet and the bottom outlet of the container are not open simultaneously. The small amount of air enclosed in the circuit at once gives up its oxygen and the inert gases consist mainly of nitrogen and a little carbon dioxide. Fresh air cannot enter the system, as it is under pressure at every point. It should be noted also that, being dry, there can be no corrosion or condensation troubles in the system. Again, as to air leakage and the danger of combustion of the coke or explosion, any leakage of air into the system would combine with the hydrogen, which is always present to a small extent, but even if it combined

only with the carbon in the coke, the quantity of coke burnt would be trifling. At a test at Keilehaven gasworks only 740 cu. ft. of oxygen were taken into the system in a day, which, in combustion represents 24 lb. of coke. The question has been closely examined by Dr. Schlaepfer and others, and Professor Eitner[8] dealt with it exhaustively, coming to the conclusion that the amount of coke consumed must be quite negligible.

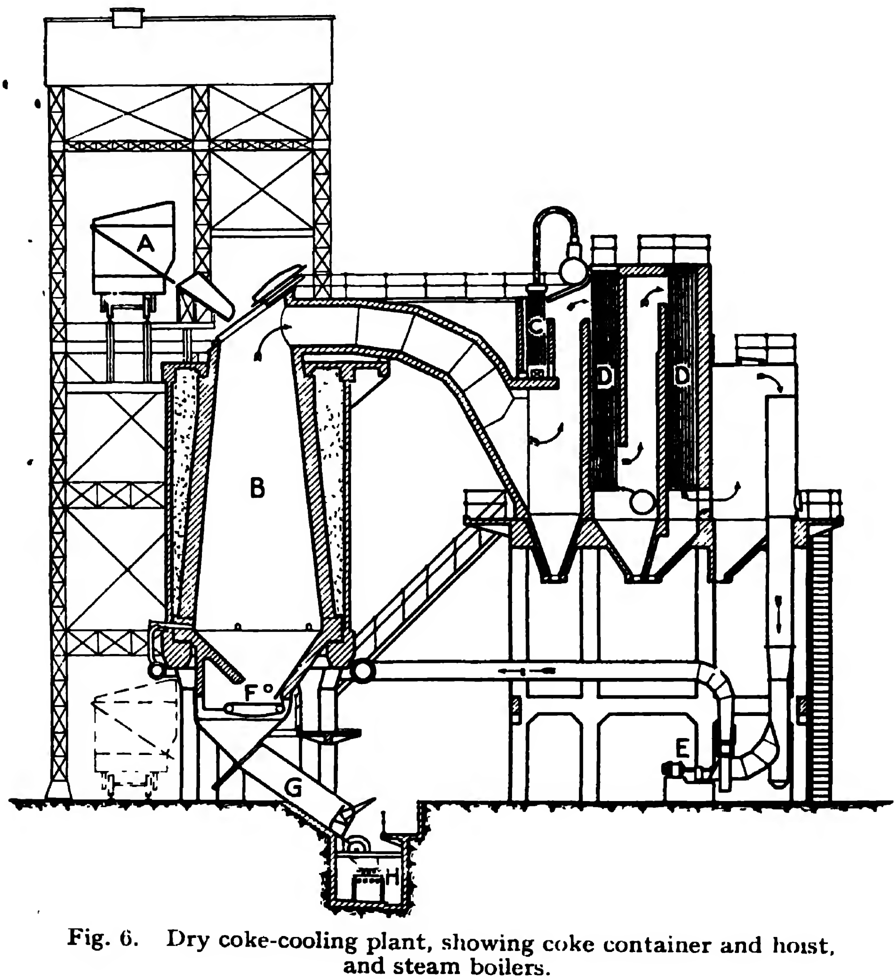

Fig. 6. Dry coke-cooling plant, showing coke container and hoist, and steam boilers.

The arrangement of the plant may take many forms, and is capable of adaptation to most existing conditions. The plant shown in Fig. 6 is designed for a battery of coke-ovens. The

[8] Eitner, Karlsruhe, *Gas- und Wasserfach*, Vol. 65, No. 46 (*vide* also J. P. Leather on this subject. Institution of Gas Engineers, June 1927, *Gas World* Coking Section, July 1927, pp. 13-15).

charge of hot coke is brought from the ovens in a coke car, A, which is built in halves. Each half-car has quick-action gates operated by compressed air, with stand-by hand-operated gear. It is lifted to the top of the container, B, by a hoist, and hauled in front of the feed-hopper of the container that is to be filled; in such an installation there are several containers, one being a stand-by. The gate of the container being opened, the contents of one half-car is run down the shoot into the container, while the other half-car is discharged into a second container. The operation of the hoist, tractor, and gates is controlled from a central cabin on the upper platform. After cooling, the coke is drawn out of the container by an extractor conveyor, F, and is run down a coke shoot, G, to be carried by the rubber band conveyor, H, to the coke screens. Each container, with its boiler, is provided with a fan, E, for circulating the inert gases. After taking up the sensible heat of the coke, the gases are cooled in passing successively the superheater, C, steam boiler, D, and the feed-water heater. Dust-catcher chambers are provided wherever necessary, with openings for depositing accumulated dust into railway wagons. There is also a fan with dust-chamber (not shown in the figure) to exhaust the dust, including that made in withdrawing coke from under the container and to deposit it in a hoppered chamber to be dumped periodically into wagons. Continuity of service may always be secured by duplication of the container and boiler unit.

Quantity of Heat Available for Raising Steam. When the early plant at Winterthur was built, followed in 1919 by the experimental plant at Schlieren Gasworks, Zurich, the specific heat of hot coke was only approximately known, and no data were obtainable. The specific heat was determined by Schlaepfer and Debrunner[9] and confirmed by various other authorities. The diagram, Fig. 7, shows the mean specific heats of various cokes. As the results are now well known, and have often been written about, it is unnecessary to consider this question further. Schlaepfer's work shows that the mean specific heat increases with the temperature of the coke, and, incidentally, that a high ash content lowers the specific heat while the presence of volatile constituents increases it.

[9] *Stahl und Eisen*, 1922, p. 1270; *vide* also Terres and Schalter in *Gas- und Wasserfach*, 1922, p. 831.

The work of these authorities has been repeatedly confirmed in actual installations and shows that, in cooling from 1,000°C. to 250°C., with boiler feed-water at 50°C., the average amount of saturated steam raised at 140 to 150 lb. per sq. in., is about 880 lb. per metric ton of coke cooled; or about 770 lb. superheated, at the same pressure, with a temperature of 350°C.

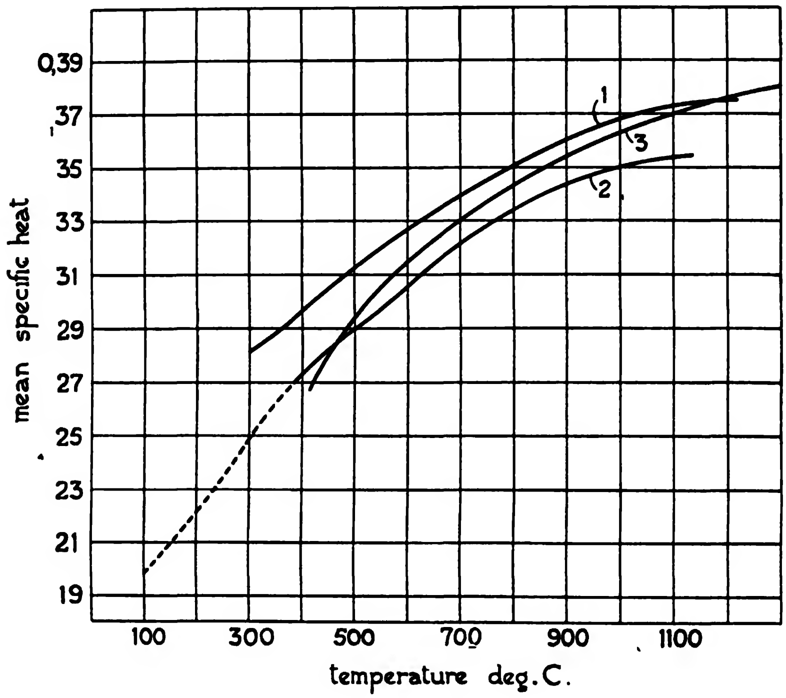

Fig. 7. Diagram showing mean specific heats of different cokes.
1. Coke oven coke with 9·45 per cent. ash (Woehler).
2. Coke oven coke with 10 per cent. ash (Debrunner).
3. Coke with 15 per cent. ash (Terres and Schaller).

Dry Cooling in relation to Coke Quality. Tests made at various installations show conclusively that dry-cooled coke is more resistant to shock and abrasion than water-quenched coke. The following comparison[10] may be taken as typical. It relates to a Saxony coal coked at the Keilehaven gasworks, part of a batch being water-quenched, and the other part dry-cooled, and then tested for abrasion by a *trommel* method.

[10] Carried out by the Erzebirgische Steinkohlen-Aktienverein, and reported in the *Monthly Bulletin of the Swiss Gas and Water Engineers Association* Vol. 4, No. 10.

Sizing.	Water-quenched coke.		Dry-cooled coke.	
0-10 mm.	18.00	53.8 per cent.	14.10	37.14 per cent.
10-25 mm.	15.60		12.64	
25-40 mm.	20.20		10.40	
40-60 mm.	16.00	46.20 per cent.	7.60	62.86 per cent.
60 and over	30.20		55.26	

These figures show that dry-cooling yielded 36 per cent. more saleable coke than wet-quenching, and that the small coke was 31 per cent. less in quantity.

At another test at Keilehaven gasworks, the coke was larger and the amount of breeze reduced by dry-cooling:—

	Wet-quenched per cent.	Dry-cooled per cent
Large	50	67
Medium (1¼ to 2½ in.)	21	17
Small	17	9
Breeze	12	7

This superiority in coke quality may be attributed to gradual cooling, as opposed to the sudden shock of contact with water; the coke is shattered by the resulting miniature explosions of steam in the pores and fissures. Over a long period the breeze was reduced[11] by nearly one-half, *i.e.*, from 14 per cent. to 8 per cent. of the total coke handled, as compared with the wet quenching previously practised.

Sulphur in Dry-cooled Coke. It has been suggested that the action of steam on the sulphides in hot coke reduces the sulphur in water-quenched coke. Careful experiments were carried out at the Mathias Stinnes Collieries to determine the differences, including sulphur content, between water-quenched and dry-cooled coke.

The report[12] made by Dr. Müller was limited to the physical properties of the coke (which are favourably commented upon), and excluded the question of the economical side of the process. Discussing the influence of the process on sulphur content, samples of water-quenched and dry-cooled cokes respectively were taken from the middle of a batch from the same oven. The total sulphur in the dry coal was 1.2 per cent.; the dry-cooled coke contained 0.914 per cent. of sulphur, and the water-quenched

[11] Sissingh. *Gas- und Wasserfach*, 1923, pp. 735 *et seq.*; *Gas World*, Coking Section, July 5, 1924, p. 17.

[12] Dr. F. Muller, *Glückauf*, August 28, 1928, pp. 1128-1132.

coke 0.857 per cent., a difference of 0.057 per cent. Considering how small a proportion of the sulphur in the coke comes down to the tuyeres in the blast furnace, and that the sulphur exists chiefly as alkaline earth sulphides that are absorbed in the slag, its influence upon the sulphur contents of the iron made is negligible. Proof of this is obtained on an industrial scale at the blast-furnace plants that have been erected. For example, the furnaces at Homécourt are fed exclusively with dry-cooled coke and the quality of the iron produced has been in no way affected, while, according to Dr. Müller, the coke consumption has been reduced by 4.17 per cent.

Incidental Advantages of Dry-cooling. The dry-cooling method dispenses with the water troubles familiar to every coke maker who quenches with water. The water is then spoilt for any other purpose and, owing to the supply being usually limited, in nearly every case it has to pass through settling tanks where the breeze is reclaimed by one means or another, and the water has then to be pumped into circulation or into high-service tanks.

The deterioration of ironwork due to the clouds of acid vapours is avoided. In a coking plant there is some escape by using remote quenching, but in a retort house the effects of quenching with water are highly destructive.

Dry-cooled coke, as compared with water-quenched coke containing, say, 7 per cent. of water, has a proportional advantage in cost of transport which, even for moderate distances, may amount to a considerable economy at the existing high railway rates. Thus, the buyer has to pay carriage on 70 tons of water in every train-load of 1,000 tons.

Economy of Dry-cooling. In the case of blast furnace practice the economy realised must resolve itself into a comparison of furnace operation with wet and dry coke respectively. Up to this time no such comparison has been possible owing to local and occasional conditions which cannot be controlled. Apart from the advantages of dry coke, for the purpose of such a comparison the physical properties of the coke other than moisture, and the characteristics of the furnace burden, do not long remain constant. A body of evidence, not conclusive, but of sufficient weight, supports the theoretical studies so far as to make it a certainty that the use of dry coke must necessarily be an economy. Apart from the absence of water, which is itself an economy, dry coke

provides the furnace with at least two valuable constants—coke moisture and carbon contents. There is less breeze and small coke made, and therefore less to eliminate in the final screening. The furnace works more regularly. Other minor economies have already been indicated, and there remains only the question of steam, which may be raised in quantity without burning fuel, its main item of cost.

The published cost of steam in eight Government factories has been assembled by Mr. Parrish,[13] and the item of fuel, taking boiler coal at £1 per ton, ranges in cost between 28d. and 43d. per ton of steam made.. The average figure is 35.5d. Now, in raising steam with the heat of coke, the expenditure on fuel, namely, 35.5d. per ton of steam, is saved, as well as some of the labour, which last, for our present purpose, we may neglect. As we have seen, the dry-cooling of coke raises, under average conditions, 880 lb. of steam per ton of coke cooled, which, at the same valuation, amounts to $\frac{880}{2240} \times 35.5\text{d.} = 14\text{d.}$ The installation therefore obtains, in the form of steam, 14d. for every ton of coke cooled, and the steam from an installation cooling 500 tons per day will therefore be worth 500 tons × 350 days × 14d. = say £10,200 per annum.

It will be seen that, at this cost, the revenue from steam will easily provide for the redemption in seven or ten years of a capital expenditure far in excess of what would be required for a dry-cooling equipment.

The site and local conditions, and the economies to be effected, will vary with every problem, and every factor that influences the question has to be examined. But to realise the figures on an assumed basis, let us suppose that we have to spend £56,000 on an installation to cool 1,000 tons of coke per day and that the initial cost is to be redeemed in seven years, by setting aside annually £8,000 for that purpose,

$$\frac{£8{,}000}{1{,}000 \text{ tons} \times 350 \text{ days}} = \text{say, 5.5d, per ton of coke.}$$

The installation at the gasworks of Utrecht, which was started at the end of 1926, cools 350 tons of coke per twenty-four hours. The plant supplied the gasworks with its requirements of saturated

13 "The Design and Working of Ammonia Stills." P. Parrish, London, 1924, p. 44.

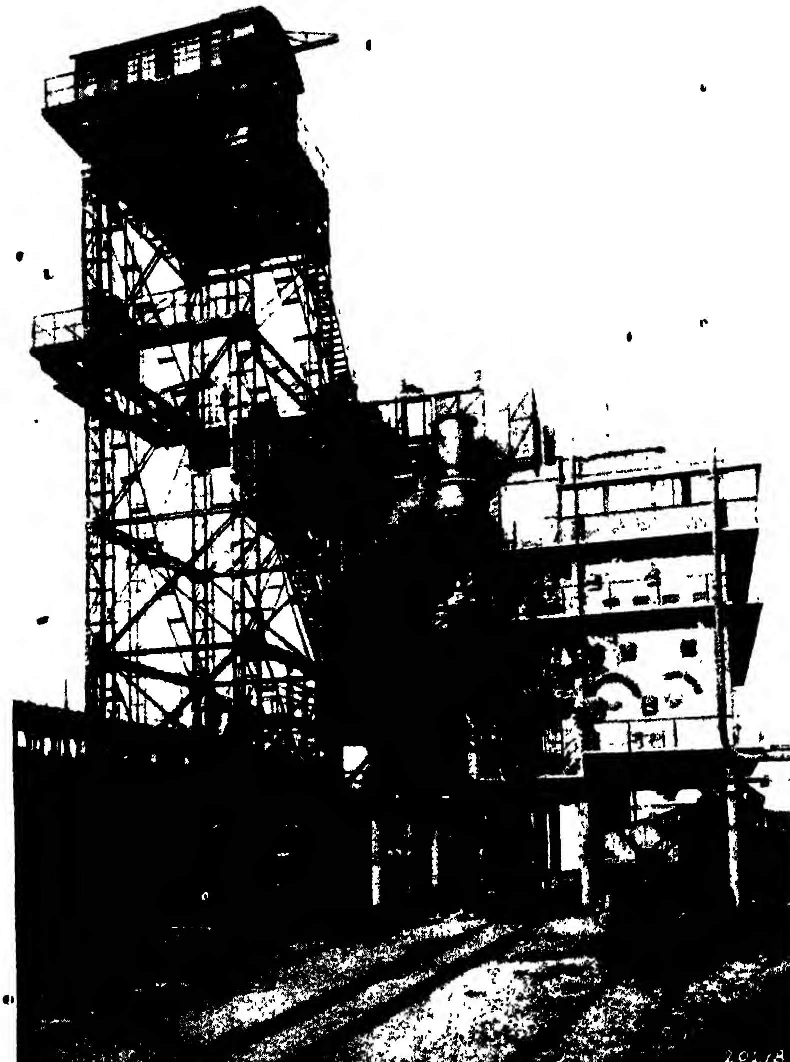

Fig. 8. Dry coke-cooling plant at the coke-oven plant of the Forges et Aciéries de la Marine et d'Homécourt, France; capacity, 1,000 tons in 24 hours. View of coke containers and boiler plant.

steam and also with steam at 200 lb. per square inch and 650°F., to drive a 750 kW. turbo-generator. When the plant is working at full capacity, this generator is capable of feeding over *one million kWh.* into the city mains.

Fig. 8 shows a view of the dry-cooling plant at the coke-ovens of the Forges et Aciéries de la Marine et d'Homécourt, designed to cool 1,000 tons of coke per twenty-four hours. There are two hoists and four container-boiler units, one of which is a stand-by. The cooling plant supplies all the steam requirements of the coke-ovens and by-product recovery plant, and there is a surplus of 180 tons of steam per twenty-four hours, which is used in turbo-generators to supply power to the steelworks.

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RÉSUMÉ

Etant donné que les charbons de bonne qualité ne sont plus bon marché et abondants, une connaissance plus approfondie du coke qui en dérive est devenue une nécessité économique et ceci a donc provoqué de nombreuses recherches sur la meilleure façon de fabriquer et d'utiliser ce produit. Cette étude ne se rapporte qu'à la question de l'extinction efficace et économique du coke.

En examinant d'abord la méthode d'extinction à l'eau, nous trouvons en premier lieu le quai à coke horizontal qui a été et est encore très répandu en Europe. Mais un moyen plus récent et plus efficace est fourni par le quai incliné d'un angle permettant au coke de descendre seul. Sur pareil quai, le "Darby quencher" peut être utilisé. L'angle d'inclinaison dépendra de la qualité du coke. Avec du coke dur, il n'est pas nécessaire de dépasser 23½°, mais il faut aller jusqu'à 28° avec du coke plus tendre. La surface inclinée du quai doit être suffisante comme longueur et comme pente pour permettre au coke de s'étaler en couche mince et uniforme sur toute sa surface quand on le défourne. Le "Darby quencher" est souvent monté sur un chariot roulant et doit permettre de diriger le jet d'eau dans l'intérieur du saumon. Trois types de quais inclinés sont décrits : sur l'un d'eux, le coke est chargé à la fourche et mis en wagon, sur le second, il est repris par un convoyeur métallique et sur le troisième il tombe sur un convoyeur Robins. Dans les deux derniers cas, des dispositions sont prises pour protéger le convoyeur contre la chute des cendrées et le coke transporté contre l'eau tombant du quai. Dans toutes les installations utilisant le "Darby quencher," la vitesse de défournement doit être réduite et même alors des lances doivent être prévues pour des extinctions locales.

On revendique pour ces quais l'avantage de permettre la mise en stock d'une certaine quantité de coke quand les moyens de transport font défaut. Leur coût de premier établissement, relativement peu élevé, les a fait adopter dans certains cas, mais de pareils quais ne conviennent pas pour des batteries en silice vu le danger qu'il y a d'endommager celles-ci avec de l'eau; le poids et la longueur des batteries modernes rendent la construction de quais inclinés très coûteuse. Dans une batterie moderne, le temps de défournement est trop court et ceci gêne trop les autres opérations qui sont à faire.

Le coke car à fond incliné déplacé par câble ou remorqué par locomotive a été très en faveur en Angleterre. Les dimensions du fond sont suffisantes pour permettre au coke de s'étaler en couches minces et regulières pour le refroidissement. On a imaginé un très grand nombre de machines pouvant circuler le long de la batterie pour recevoir le coke chaud tel qu'il est défourné, certaines avec dispositif d'arrosage, d'autres avec réservoirs dans lesquels le coke tombant est immergé, mais nous ne pouvons décrire que la machine Greensmith.

La pratique de l'extinction à distance est presque générale en Amérique et commence à se répandre dans les installations modernes en Europe. Le coke est défourné rapidement, sans arrosage, dans un car d'extinction à surface de plancher limitée, qui est conduit sous une tour où l'extinction se fait avec une quantité d'eau determinée. La tour est à quelque distance des fours et est prévue pour que l'extinction et l'évaporation de l'eau du coke se fasse rapidement, de sorte que les fours, les constructions avoisinantes, ainsi que le personnel ouvrier, sont à l'abri des nuages de vapeur d'eau et des vapeurs

acides. Quand le coke est égoutté, il est ramené à un quai de refroidissement d'où il est repris par des rouleaux distributeurs et déversé sur un convoyeur Robins qui le conduit au criblage.

Dans l'industrie du gaz, le coke est ordinairement éteint à l'eau pendant qu'il est entraîné le long du bâtiment à cornues. La qualité cokéfiante des charbons est souvent telle qu'il est impossible d'obtenir une teneur en eau faible et constante, mais surtout dans le cas de cornues discontinues, certaines méthodes employées dans les cokeries permettraient d'éteindre un poids déterminé de coke avec une quantité d'eau bien définie de façon à assurer une humidité faible et uniforme. On prétend que cette méthode est incomplète si elle n'est pas suivie d'un étalage du coke éteint en couches de faible épaisseur, de façon que l'eau soit évaporée par la chaleur interne du coke, et si on ne lui donne pas le temps de se refroidir.

A tous les points de vue, l'eau dans le coke est un ennui. Il est prouvé que les fabricants de coke ont constamment amélioré les méthodes d'extinction à l'eau, mais aux hauts-fourneaux on se plaint encore que l'humidité soit plus élevée quand on le reçoit que ne l'admettent les fabricants de coke. Au cours d'une enquête faite au sujet du fonctionnement des hauts-fourneaux en Angleterre, Fred Clements a choisi un certain nombre d'entre eux où la teneur en eau moyenne du coke utilisé était de 6,43%. Certains cokes de qualité inférieure doivent avoir une teneur en eau encore plus élevée. Il est évident que le coke à teneur en eau élevée et irrégulière ne convient pas du tout pour la production économique de la fonte ni pour fondre le fer dans les cubilots. Ceci est facile à démontrer dans le cas de la fonderie ainsi que pour l'emploi du coke pour le chauffage et l'usage domestiques, mais dans le fonctionnement d'un haut-fourneau les conditions d'exploitation sont telles que l'économie résultant de l'emploi de coke refroidi à sec ne peut pas être démontrée aussi facilement. Tant de facteurs affectent la marche d'un haut-fourneau que même par des essais comparatifs en employant alternativement du coke éteint à l'eau et du coke éteint à sec, il n'est pas toujours possible de prouver l'avantage et l'économie résultant du refroidissement à sec. Là où le coke de haut-fourneau est refroidi sans eau, il est sec et de qualité constante; celui qui est refroidi à l'eau n'est jamais constant ni comme teneur en eau ni comme teneur en carbone. Il est admis que le coke sec permet une consommation constante du coke et une marche régulière du fourneau.

Par le procédé Sulzer d'extinction à sec, il est très évident qu'avec une même qualité de charbon, on obtient une plus grande proportion de gros coke que par l'extinction humide. Ceci peut être attribué au refroidissement graduel supprimant le choc brusque de l'eau froide avec les explosions en miniature qui en résultent dans les pores et les fissures.

L'appareil Sulzer consiste en un étouffoir pour coke incandescent contre lequel se trouve une chaudière, faisant tous deux partie d'un circuit parcouru d'une façon continue par les gaz inertes mus par un ventilateur. Ces gaz enlèvent la chaleur au coke, puis la cèdent à l'eau de la chaudière. Les conditions de marche sont telles que les rentrées d'air, la combustion du coke et les explosions sont impossibles. Un exemple d'installation est représenté et décrit.

En refroidissant le coke de 1.000 à 250°C. la quantité moyenne de vapeur saturée produite avec de l'eau d'alimentation à 50° est environ de 400 k., à la pression de 10 atmosphères par tonne de coke refroidi.

Le procédé de refroidissement à sec élimine les inconvénients dus à l'eau que rencontre tout fabricant en faisant l'extinction à l'eau. L'eau est de toute façon inutilisable telle quelle et elle doit habituellement passer par des bassins de décantation pour la récupération des cendrées, puis une pompe la refoule vers la distribution ou le château d'eau.

La détérioration des charpentes métalliques par les vapeurs acides est supprimée. Enfin, le coke sec a l'avantage, pour ce qui concerne le coût du transport, sur un coke qui contient, disons, 7% d'eau.

Le rapport est illustré de figures représentant les différentes méthodes d'extinction par l'eau, du procédé à sec et de quelques installations qui ont été construites.

THE FUNDAMENTAL ASPECTS OF COMBUSTION

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Paper No. G8

CONTENTS

INTRODUCTION

The subject of this paper covers such a wide field that it is possible only to refer briefly to those aspects of it which appear to be of more general interest The matter is dealt with in four sections, namely :—I. Thermal considerations. II. The mechanism of combustion. III. Explosive combustion, and IV. Catalytic and incandescent surface combustion. In each section an endeavour has been made to indicate the present state of knowledge and the directions in which research is leading.[1]

SECTION I. THERMAL CONSIDERATIONS

HEATS OF COMBUSTION

The primary consideration in a combustion process is the heat developed in the oxidation (complete or otherwise) of the combustible

[1] For more detailed information concerning recent researches, reference may be made to Bone and Townend's "Flame and Combustion in Gases," Longmans, Green & Co. Ltd., 1927.

concerned. A complete knowledge of this depends on the principle enunciated by Hess in 1840, which postulates that the heat[2] evolved in a chemical reaction is independent of the steps by which it is effected and of the order in which these steps succeed one another. Thus, for example, knowing the heat of combustion of carbon to the dioxide to be 97 K.C.U. per gram molecule and that of carbon monoxide to the dioxide to be 68 K.C.U. per gram molecule, the simple deduction may be made that the oxidation of carbon to the monoxide evolves (97-68)=29 K.C.U. per gram molecule.

It may be shown in like manner that the heat of combustion of a hydrocarbon is the difference between (*a*) the heat available from the complete oxidation of its separate constituent elements, and (*b*) its heat of chemical formation.

Many eminent investigators have devoted their attention to the exact determination of heats of combustion; the principal researches being those of Dulong (1830-40), Thomas Andrew (1848), Favre and Silbermann (1842-3), Berthelot (1875-9), Schuller and Wartha (1877), Than (1881), and Julius Thomsen (1882-6)[3].

The following are Thomsen's results for the gram molecular heats of combustion of the principal combustible gases and vapours, when burnt at constant pressure to water and carbon dioxide at 18°C., the method employed being that of burning the gases in a combustion chamber immersed in a calorimeter, the condensed water being collected and weighed.

Gas.	*K.C.U.*	*Vapour.*	*K.C.U.*
Hydrogen[4]	68·4	Benzene	799
Carbon monoxide[4] ...	68·0	Toluene	956
Methane	212·0	Methyl alcohol ...	182
Ethane	370·5	Ethyl alcohol ...	340
Propane	529·0	Ethyl ether ...	660
Ethylene	333·3		
Propylene	492·7		
Acetylene	310·0		
Cyanogen	259·6		

[2] It would be better to substitute the word "energy" for "heat" in considering Hess's principle, since the total energy liberated in a given case of combustion comprises both that which appears as kinetic energy (temperature) and that which is directly radiated away.

[3] The reader is referred to a series of articles by S. Robson in the *Journal of Gas Lighting*, Vol. CXXXII. (1919), pp. 431, 478, 532, 582 and 635, containing a detailed review of the methods employed and the results obtained by these investigators.

[4] Travers (*J. Inst. Fuel*, Nov., 1927) gives a critical survey of the determination of heats of formation of steam and carbon dioxide. He considers 68·345 K.C.U. to be the best value for steam at 18°C. and similarly 67·900 K.C.U. that for carbon dioxide.

It should be noted with regard to organic compounds that an increase of CH_2 in ascending an homologous series corresponds with a constant increase of as nearly as possible 158·5 K.C.U. in the molecular heat of combustion.

Heat of Combustion at Constant Volume. When a change of molecular volume occurs in combustion the heat of combustion varies according to whether it is measured under constant volume or constant pressure conditions, the difference being equivalent to the work done on contraction. This may be expressed as follows:—

$$Q_p = Q_v + mRT$$

where m=the number of reacting molecules less the number of molecules in the products, R=the gas constant and T=the absolute temperature at which the heat of combustion is measured. Thus in the case of carbon monoxide measured at 18°C.

$$Q_v = 68{\cdot}000 - (1 \times 1{\cdot}98 \times 291) = 67{\cdot}424 \text{ K.C.U.}$$

Influence of Temperature on Heat of Combustion. It is also important to bear in mind that heats of combustion depend on the temperature of the reactants.

Thus in the case of a reaction $A \rightarrow B$ at temperatures T_1 and T_2

$$QT_2 = QT_1 + (T_2 - T_1)\ (C_A - C_B)$$

where QT_1 and QT_2 = the heats of combustion at T_1 and T_2, respectively, and C_A and $\bar{C}_B$ = the mean molecular heat capacities of the reactants and products respectively between the temperatures T_1 and T_2. These values at constant volume are shown in Fig. 1. (If it is desired to use the corresponding figures for constant pressure conditions an addition of 1·98 calories per gram molecule should be made.)

For example, whereas the heats of combustion at constant pressure of hydrogen and carbon monoxide at 18°C. are 57·3 (net) and 68·0 K.C.U. respectively, at 1,000°C. they are 59·20 and 67·54 K.C.U. More marked is the effect of temperature on the heat of reaction in the case of the water-gas reaction $CO + OH_2 \rightleftharpoons CO_2 + H_2 + 10{\cdot}5$ K.C.U. A simple calculation based on Hess's principle, from heats of combustion of hydrogen and carbon monoxide at 18°C. shows it to be 10·5 K.C.U. At 1,000°C., however, it is only 8·21 K.C.U.

The Function of Gaseous Equilibria in Combustion. According to the law of mass action any chemical interaction such as

$$A + B \rightleftharpoons C + D$$

is theoretically reversible (and often practically so) at all temperatures. The absolute amount by which the reaction as a whole can

proceed is controlled simply by the relative velocities of each re-action (either left to right or right to left) at any specified tempera-ture. Thus at a temperature T, $V_1 = k_1 (A)(B)$ and $V_2 = k_2 (C)(D)$. When $V_1 = V_2$ a state of dynamic equilibrium is reached. Then $k_1(A)(B) = k_2 (C)(D)$

$$\text{or } \frac{(A)(B)}{(C)(D)} = \frac{k_2}{k_1} = K \text{ (the equilibrium constant).}$$

It should also be mentioned that, according to the well-known Van't Hoff-Le Chatelier principle of mobile equilibrium, any change in the factors of equilibrium (*e.g.*, concentration, temperature and, in cases involving molecular volume change, likewise pressure) from outside must be followed by a reverse change within the system. Thus a rise in temperature will cause the equilibrium to shift in the direction of heat absorption; and, similarly, if there is a change in the number of molecules in the reaction, increase of pressure will effect a shift of the equilibrium in the direction of decreasing volume.

Chemical equilibrium is of great importance in combustion pro-cesses. Thus, for example, although it is usual to regard the oxidation of hydrogen and carbon monoxide as proceeding com-pletely to steam and carbon dioxide this can only be achieved at comparatively low temperatures. For, at temperatures above 1,500°C. (say) the reverse action (dissociation) begins to play a measurable part. This is particularly marked in the case of carbon dioxide.

Perhaps the most important reversible reaction occurring in com-bustion processes is the water-gas reaction

$$CO + OH_2 \rightleftharpoons CO_2 + H_2 + 10{\cdot}5 \text{ K.C.U.}$$

for whenever, as the result of incomplete combustion the oxides of carbon, steam and hydrogen are present in flames, they constitute this active reversible system.

The values of the equilibrium constant

$K = \dfrac{(CO)\ (OH_2)}{(CO_2)\,(H_2)}$ as measured experimentally by Hahn[5] are follows:—

Temp. °C.	K	Temp. °C.	K
786°	0·81	1086°	1·95
886°	1·19	1205°	2·10
986°	1·54	1405°	2·49

[5] *Zeit. Phys. Chem.* 43, p. 705; and 44, p. 513.

From such values Hahn deduced the following equation—

$$\log_{10} K = \frac{-2232}{T} - 0{\cdot}08463 \log_{10} T - 0{\cdot}0002203T + 2{\cdot}5084$$

where $T =$ the absolute temperature. From this equation the following values of K would be predicted.

Temp. °C. ...	1005°	1205°	1405°	1600°
K	1·63	2·54	3·43	4·24

Haber has determined the water-gas equilibrium in open flames, finding values between 1250° and 1500°C. which agreed with those predicted by Hahn's equation. Corresponding values have also been determined from the rapidly cooled products in gaseous explosions.[6]

It is not possible to refer here to all the various reversible reactions which may play more or less important roles in combustion. The following may be mentioned and some of them will be referred to later on:—

(*a*) $C + OH_2 \rightleftharpoons CO + H_2 - 29$ K.C.U.
(*b*) $C + 2OH_2 \rightleftharpoons CO_2 + 2H_2 - 19$ K.C.U.
(*c*) $2CO \rightleftharpoons C + CO_2 + 39$ K.C.U.
(*d*) $CH_4 \rightleftharpoons C + 2H_2 - 21{\cdot}7$ K.C.U.
(*e*) $2CO + 2H_2 \rightleftharpoons CH_4 + CO_2 + 61$ K.C.U.
(*f*) $CO + OH_2 \rightleftharpoons CO_2 + H_2 + 10{\cdot}5$ K.C.U.
(*g*) $2H_2 + O_2 \rightleftharpoons 2H_2O + 58{\cdot}0$ K.C.U.
(*h*) $2CO + O_2 \rightleftharpoons 2CO_2 + 68{\cdot}0$ K.C.U.

Influence of Temperature on Gaseous Equilibria. The variation of the equilibrium constant K in any reversible reaction with the absolute temperature T is given by the Van't Hoff isochore,

$$\frac{d \log_e K}{d T} = \frac{Q}{RT^2}$$

where Q is the heat of reaction and R the gas constant. On integration and assuming the heat of reaction to be independent of temperature, this equation becomes

$$R \log_e K = \frac{Q}{T} + C$$

whence, if the heat of the reaction and the equilibrium conditions at any one temperature be known, it is possible to calculate the corresponding K value at any other temperature.

[6] Dixon, *Trans. Chem. Soc.*, 1884; Andrew, *Trans. Chem. Soc.*, 105 (1914), p. 444; Bone, *Phil. Trans.* A 215 (1915), p. 275; Townend, *Proc. Roy. Soc.*, A, 116 (1927)), p. 637.

For approximate calculation of equilibria the simplified form of the Nernst approximation formula given below is also of value,

$$\log K_p = \frac{Q}{4{\cdot}571\ T} + \Sigma_n\ 1{\cdot}75 \log T + \Sigma_n C.$$

where Q = the heat of reaction at ordinary temperature.

Σ_n =the algebraic sum of the molecular volumes (those on the right being positive, those on the left negative, the positive heat change also being on the right hand side),

$\Sigma_n C$ =the algebraic sum of the Nernst chemical constants. These can be found in most text books on chemical thermodynamics.

Combustion Temperature as Affected by Dissociation and Specific Heats

The principal factors controlling the temperatures attained in combustion are (*a*) the rate of combination of the reacting gases in any particular circumstance, (*b*) the mean heat capacities of the gaseous products, (*c*) dissociation, and (*d*) heat losses due to conduction and radiation.

Dissociation. In the case of two combining gases producing a dissociable product it is clear that if the average temperature of the system exceeds that at which dissociation begins, a percentage of the heat of combustion will not be available at such temperature.

The explosion method (referred to more fully later on) has been that most used for the determination of the degrees of dissociation at very high temperatures. Thus Bjerrum observed the difference in the pressures (temperatures) developed when theoretical ($2H_2+O_2$ or $2CO+O_2$) mixtures were exploded first with addition of nitrogen, and then with a corresponding addition of one of the reacting gases so as to suppress dissociation. For according to the principles already enumerated the relation between the concentration of a gas and that of its dissociated products is represented at any one temperature by an equilibrium constant K. In the case of carbon dioxide, $K = \frac{(CO)^2\,(O_2)}{(CO_2)^2}$; therefore addition of excess of either carbonic oxide or oxygen to a theoretical mixture must cause an increase in the equilibrium concentration of carbon dioxide at the maximum temperature attained. On the other hand, a corresponding addition of nitrogen has no influence on the phenomenon.

The following data for the dissociation of steam and carbon dioxide respectively at various temperatures and pressures have been

deduced from experimental results by Nernst and Wartenburg and by Bjerrum:—

DISSOCIATION OF STEAM AND CARBON DIOXIDE

Pressures (Atmospheres).	0·1	1·0	10	100
Temp. (Abs.)		Steam.		
1500	0·043	0 02	0·009	0 004
2000	1·25	0·58	0·27	0·125
2500	8·84	4·21	1·98	0·927
3000	28·4	14·4	7·04	3·33
3500	53·1	30·9	16·1	7·79
		Carbon Dioxide.		
1500	0·104	0·0483	0·0224	0·0104
2000	4·35	2·05	0·96	0·445
2500	33·5	17·6	8·63	4·09
3000	77·1	54·8	32·2	16·9
3500	93·7	83·2	63·4	39·8

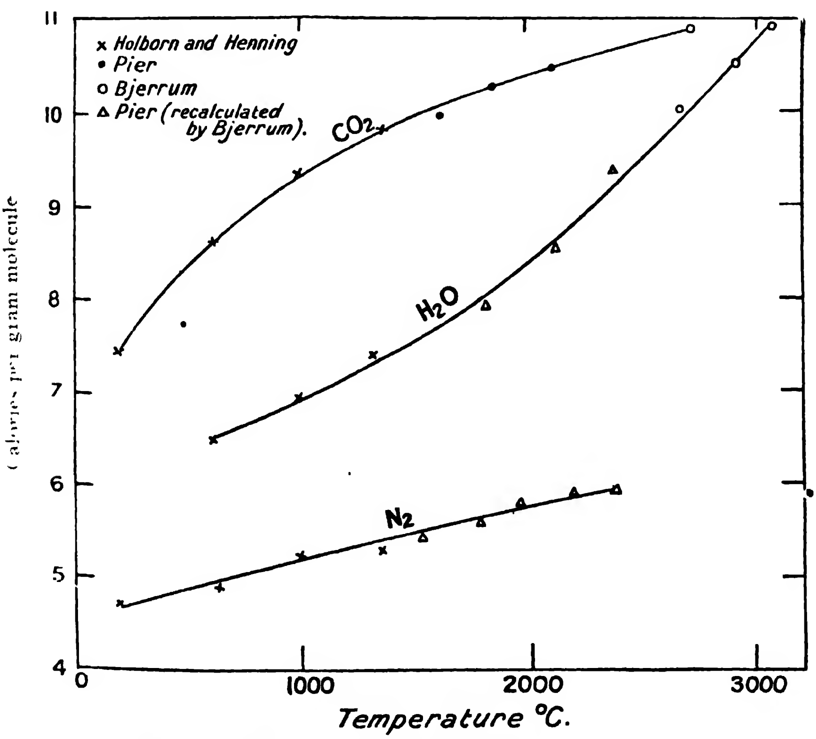

Fig. 1. Mean Molecular Heat Capacities. (Bjerrum.)
(From "Flame and Combustion in Gases.")
(By kind permission.)

Mean Molecular Heat Capacities. Having estimated the dissociation occurring in explosions the mean molecular heat capacities of the gaseous products may be calculated from known pressure development. In Fig. 1 are given curves showing the nature of the increase of mean molecular heat capacity with temperature of the gases carbon dioxide, steam and nitrogen. It may be mentioned that the rise in the case of nitrogen is of the same order as in the case of all other diatomic gases, also that the molecular heat capacities of monatomic gases, *e.g.*, argon, do not change with temperature (having one degree of freedom only) and have a constant value of 2·98 cals. per gram molecule.

The actual values given for dissociation and molecular heat capacity cannot be considered as final, as in such calculations certain assumptions in regard to heat losses are inevitable. Recent papers on the subject have been published by Fenning and Tizard,[7] Maxwell and Wheeler[8] and Newitt.[9]

RADIATION FROM FLAMES

The molecules of a gas possess three types of energy, namely, (1) translational or kinetic, due to the external movement of the molecules as a whole—causing temperature and pressure, (*b*) rotational or movements of the atoms within each molecule, and (*c*) vibrational, which is primarily connected with the absorption and emission of radiation. Hence the total energy of a molecule may be expressed as the sum of its three types.

$$\Sigma = k + r + v.$$

It will thus be seen that part of the total energy developed by the combustion of a gas in flames is directly radiated and consequently does not appear as sensible heat in the products or contribute to the flame temperature.

According to Planck's conception, exchange of radiant energy is not continuous, as was formerly supposed, but takes place in multiples of a small energy unit, called the quantum. This is not a fixed quantity of energy but a function of the vibration frequency, its magnitude being $\epsilon = h\nu$, where ν = the frequency, and h a natural constant $= 6\cdot5 \times 10^{27}$ erg-seconds. The quantum corresponding to a high frequency in the ultra violet would be very large compared with that corresponding to low frequency in the infra-red. It is estimated that upwards of 90 per cent. of the total radiation from ordinary flames is in the infra-red.

[7] *Proc. Roy. Soc.* A, 115 (1927), p. 318.
[8] *Trans. Chem. Soc.*, 1928, p. 15.
[9] *Proc. Roy. Soc. A*, 119 (1928), p. 464.

It has been shown[10] that the infra-red radiation from different kinds of non-luminous flames is due to incipiently formed (or forming) carbon dioxide and steam molecules. Such emission occurs in well-defined bands; in the case of carbon dioxide mostly at 4·4 μ and to a less degree at 2·7 μ, and in the case of steam mostly at 2·8 μ.

Helmholtz has given the following figures for the relative amounts of radiation per litre of gas burnt, emitted by flames of given size, the air supply in each case being adjusted so that the flame was just non-luminous.

	Relative radiation per litre.
Hydrogen	74
Carbonic oxide	177
Methane	327
Ethylene	570

It will be observed from such figures that the radiating power of a hydrocarbon is due to the number of carbon dioxide and steam molecules produced. Thus in the case of methane:—$177+(2\times74)=325$. This aspect of the subject has been examined recently by Haslam, Lowell and Hunneman,[11] to whose papers the reader is referred. Helmholtz took the view that the radiation from such flames is due to chemical rather than to thermal cause. Paschen and others have maintained that it is purely thermal. It seems now generally recognised that as the outcome of the initial encounters betewen the molecules concerned the radiation emitted is probably chemical (chemi-luminescence). After a state of molecular "equilibrium" has been attained, however, it is probably controlled by temperature only. In luminous flames, in addition to chemical radiation, there is also that emitted by the incandescent carbon. This being 'black body radiation," the emission obeys the Stefan-Boltzman law and is therefore proportional to the fourth power of the absolute temperature.

Callendar has shown that the energy radiated away from flames of coal-gas with the air supply adjusted in substantially the proportions required for complete combustion varied from 10 to 15 per cent. of the total energy of combustion as the diameter of the burner was increased from 1 to 4 in. Also, on increasing the depth of the flame the emission per unit area gave results in agreement with the exponential expression $R = 473(1 - e^{-0\cdot054X})$ where $X=$ the thickness of the flame.

[10] *e.g.* Julius, *Die Licht und Wärmestrahlung verbrannter Gaze*, 1890.
[11] *Ind. Eng. Chem.* 17 (1925), p. 272; also Haslem and Boyer, *Ind. Eng. Chem.* 19, (1927), p. 4 and Hottel, p. 888.

Since 1911, W. T. David has carried out a series of investigations into the nature of the emission of radiation in gaseous explosions.[12] His experiments indicate that during the whole course of coal gas-air and hydrogen-air explosions up to 26 per cent. and 16 per cent. respectively of the heats of combustion are lost by radiation; up to the moment of maximum pressure, however, the corresponding percentages are 3·3 and 0·5 respectively. Recently David[13] has demonstrated that the rate of combustion of certain gaseous mixtures may be speeded up by passing infra-red radiation into them through a fluorite window. Thus in mixtures of carbonic oxide and air the introduction of $4 \cdot 6\,\mu$ radiation, which is absorbed by carbonic oxide, was found to speed up combustion though other kinds of radiation had no effect.

The infra-red emission from explosions of carbonic oxide-oxygen explosions has also formed the subject of a recent experimental enquiry by W. E. Garner and C. H. Johnson, to whose work we shall refer in the next section.

SECTION II. THE MECHANISM OF COMBUSTION

The Combustion of Carbon

In view of the fact that a diamond burns when strongly heated in oxygen forming carbon dioxide without any visible flame, it was formerly believed that such is the initial interaction, the monoxide subsequently resulting only when the primary product comes in contact with an excess of incandescent carbon, thus:—

$$(1)\ C + O_2 = CO_2;\quad (2)\ CO_2 + C = 2CO$$

The correctness of this view was challenged by Sir Lowthian Bell (1872) and by C. J. Baker (1887). Also, when H. B. Baker (1888) demonstrated that highly purified charcoal, heated to redness in carefully dried oxygen, burns with extreme slowness and without flame yielding principally the monoxide, and moreover, in the absence of moisture, carbon dioxide is not reduced by carbon under the same conditions, the opposite conclusion seemed the more probable.

Subsequently, experiments of Lang,[14] however, revived the view that carbon is first burnt to the dioxide and although doubt was thrown on Lang's conclusions by some new experiments by H. B. Dixon,[15] no decisive proof of either view was forthcoming.

[12] *Phil. Trans. A.* 211 (1911), p. 375; *Proc. Roy. Soc. A*, 98 (1920), p. 183 and p. 303; *Phil. Mag.* 39 (1920), p. 84; 40 (1920), p. 318.
[13] *Proc. Roy. Soc A*, 108 (1925), p. 618.
[14] *Zeit Phys. Chem* (1888), p. 161.
[15] *Trans. Chem. Soc* 75 (1899), p. 630.

Within recent years the subject has been thoroughly reinvestigated by Rhead and Wheeler[16] over a temperature range extending from 100° up to 900°C. A preliminary series of experiments at various selected temperatures between 250°C. and 500°C. failed to afford any conclusive evidence of the exclusive formation of either the monoxide or the dioxide, and led to the conclusion that both are produced simultaneously. Further investigation over a much wider range of temperature afforded much presumptive evidence that such simultaneous production of the two oxides was the result of the decomposition of an unstable "physico-chemical complex" C_xO_y, which was regarded as the immediate and initial product of the oxidation of carbon.

Langmuir,[17] who studied the action of oxygen upon carbon at very low pressures, was unable to detect the formation of any carbon monoxide at 950°C.; on the other hand, the carbon dioxide formed did not account for the whole of the oxygen initially present. At 1425°C., however, carbon monoxide was detected. The conclusion drawn was that part of the oxygen formed an adsorbed layer in chemical combination with the carbon as Rhead and Wheeler had suggested and part reacted to form the dioxide as the outcome of the decomposition of the adsorbed layer.[18]

Some recent work by M. Shah in H. B. Baker's laboratory suggests that the initial stage of the combustion of charcoal by either oxygen or nitrous oxide involves merely a "fixation" of oxygen rather than the formation of any definite C_xO_y complex.

It seems probable that when air comes in contact with incandescent carbon as in a coke fire the sequence of events is (1) a "fixation" of oxygen at the carbon surface, (2) the simultaneous evolution therefrom of oxides of carbon, (3) the rapid attainment and adjustment of a mobile equilibrium in the reversible system $2CO \rightleftharpoons C + CO_2$ in consonance with the temperature in each successive layer as the mixed gases ascend through the fire.

The Reversible System $2CO \rightleftharpoons C + CO_2$. Rhead and Wheeler[19] have made a very thorough examination of the reversible system $2CO \rightleftharpoons C + CO_2$ over a wide range of temperature and pressure.

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[16] *Trans Chem. Soc.* 101 (1912), pp. 101, 846; and 103 (1913), pp. 103, 461.

[17] *J. Amer. Chem. Soc.* 37 (1915), p. 1154.

[18] A very good summary of this branch of the subject has been given by Haslam, *J. Inst. Fuel*, 1 (1926), p. 18.

[19] *Trans. Chem. Soc.* 97 (1910), 2718; and 99 (1911), 1141.

At atmospheric pressure the relationship between the concentrations of carbon monoxide (C_1) and carbon dioxide (C_2) was found to be as follows:—

$$\frac{19500}{T} + \log. \frac{C_1^2}{C_2} = K$$

The value of K increases from 19·85 at 800°C. up to 20·17 at 1100°C. Also, in accordance with the principle of mobile equilibrium the equilibrium percentages of carbon dioxide were found to increase as the pressure of the gases was raised. It was further shown that the velocity at which carbon dioxide is reduced by carbon at temperatures above red heat is always many times faster than that at which carbon monoxide decomposes at the same temperature.

Interactions of Steam with Incandescent Carbon. In incomplete combustion an important part is played by steam in its interactions with carbon. Thus, at low temperatures (500° to 600°C.) the chief products are carbon dioxide and steam, according to the equation (*a*) $C + 2H_2O = CO_2 + 2H_2 \ldots - 19{\cdot}0$ K.C.U. At temperatures above 1000°C. the main reaction is as follows, (*b*) $C + H_2O = CO + H_2 \ldots - 29{\cdot}0$ K.C.U.

THE COMBUSTION OF CARBONIC OXIDE

Early Theories. Since H. B. Dixon's discovery in 1880 that thorough drying of a mixture of carbonic oxide and oxygen by prolonged contact with phosphoric anhydride renders it non-explosive when a spark of moderate intensity is passed through it, the mechanism by which the oxidation of this combustible gas is effected has always been a matter of great interest to chemists. For some years, purely chemical theories, introducing the idea that steam molecules act as carriers of oxygen, were much in favour. Dixon himself supposed that, carbonic oxide and oxygen being mutually inert in flames, steam is necessary to the process, itself being continuously decomposed and regenerated during the combustion, thus:—

$$(1) \quad CO + OH_2 = CO_2 + H_2$$
$$(2) \quad 2H_2 + O_2 = 2H_2O, \text{ etc.}$$

Traube (1882) and Mendeléeff (1891) put forward a modification of Dixon's view postulating the intermediate formation of hydrogen peroxide during the combustion of carbon monoxide. Also H. E.

Armstrong, who contends that chemical interactions cannot occur between two perfectly pure substances but require an electrolyte to form a "closed conducting circuit," supposed that the presence of steam provides the necessary conditions for the passage of the current, as follows:—

Before.			*After.*	
CO	OH_2	0	CO_2	H_2O
CO	OH_2	0	CO_2	H_2O

Alternative physical explanations have not been wanting. As far back as 1886 Lothar Meyer put forward the view that a far higher temperature is required to initiate interaction between carbonic oxide and oxygen than between carbonic oxide and steam; so that, whereas the latter is easily initiated by a spark of low intensity the former requires one of high intensity. Later on, the researches of Dixon, Strange and Graham and of Smithells and Dent suggested that when carbonic oxide is freshly formed in a flame, and therefore in an "ionised" condition, it will combine directly with oxygen without the intervention of steam.

In 1893 J. J. Thomson pointed out that the forces holding the atoms together in a molecule are electrical in character, the presence of drops of any liquid such as water of high specific inductive capacity would probably cause a sufficient loosening of the bonds between the atoms to render the molecule much more reactive. In 1910 he again reminded chemists that combustion is concerned not only with atoms and molecules but also with electrons.

Recent Researches. Much fresh information on the subject has been forthcoming in recent years as the outcome of researches carried out principally by W. A. Bone and F. R. Weston,[20] at the Imperial College, London.

In view of W. A. Thornton's discovery in 1914, reference to whose work will be made in the next section, that for given sparking conditions (*e.g.*, electrodes, type of discharge, voltage, etc.), a certain "minimum spark energy" is required to ignite a given explosive mixture, it seemed possible that Dixon's sparks had been too feeble to ignite his well-dried mixture, and that even the driest mixture might be exploded if sparks of sufficient intensity be used. On putting the matter to the test of experiment this anticipation proved to be correct, the minimum spark energy required to ignite a calcium chloride-dried $2CO + O_2$ mixture being some thirty times

[20] *Proc. Roy. Soc. A*, 110 (1926), p. 615.

greater than for the same mixture when saturated with water vapour at the room temperature. This effect is brought out clearly in Fig. 2, in which the minimum igniting capacity of a condenser discharge at 110 volts is plotted against the percentage water vapour content of the $2CO+O_2$ mixture.

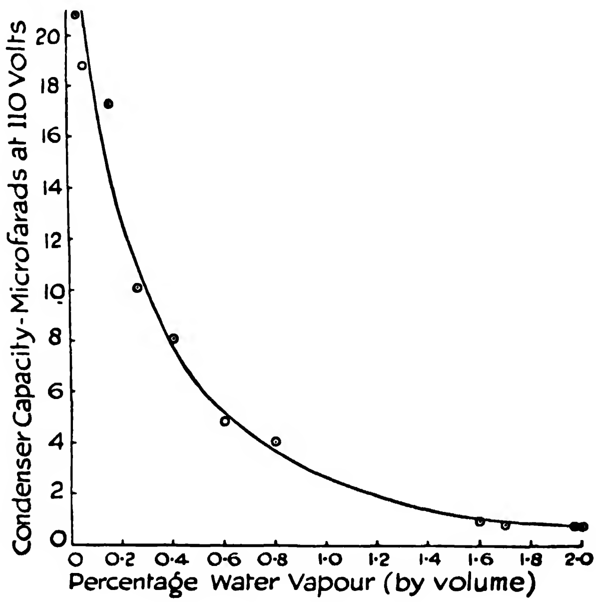

Fig. 2.

(From "Flame and Combustion"— By kind permission.)

Finally, it was shown that even a rigidly-dried mixture of carbonic oxide and oxygen can be exploded at atmospheric pressure if a sufficiently powerful condenser discharge be employed. (For a full description of the elaborate experimental ritual observed in carrying out these experiments the original papers should be consulted.) Some idea of how powerful a spark was needed may be gathered from an estimate of G. I. Finch, who was in charge of the firing arrangements, that in the circuit employed the peak current of the first oscillation of the discharge spark from a 0·75 microfarad condenser at 970 volts would be certainly not less than 700 amperes. Moreover, it should be stated that when the discharge from a 0·5 microfarad condenser failed to ignite the mixture, the spark simply passed across the gap between the electrodes without any sign

whatever of a halo or such like appearance. The results of four experiments are summarised below.

EXPERIMENTS UPON THE EXPLOSION OF A RIGIDLY DRIED $2CO+O_2$ MIXTURE (*Bone and Weston*).

Experiment No.	Drying Period (weeks)	Details of Firing Trials	Per cent. CO burnt.
1	24	(1) With 0·5 microfarad at 970 volts = 0·235 Joule. *No ignition.* (2) With 0·77 microfarad at 970 volts = 0·362 Joule. *Instant explosion.*	74·3
2	25	(1) With 0·11 microfarad at 970 volts = 0·052 Joule. *No ignition.* (2) With 0·50 microfarad at 970 volts = 0·235 Joule. *No ignition.* (3) With 1·0 microfarad at 970 volts = 0·47 Joule. *Instant explosion.*	77·2
3	27	With 2·0 microfarads at 970 volts = 0·94 Joule. *Instant explosion.*	88·0
4	31	With 5·0 microfarad at 970 volts = 2·35 Joule. *Instant explosion.*	87·5

It may be noted that the greater the energy (up to a limit) of the spark which ignited the mixture the more complete was the combustion in the subsequent explosion.

It may therefore be concluded that there is some property of the electric spark, presumably its ionising power, which if only developed strongly enough, can overcome the high resistance of such an extremely dry mixture to ignition and by virtue of which can, so to speak, compensate the system for the absence of water vapour.[21]

W. A. Bone and R. P. Fraser[22] have also shown that pressure will overcome the reluctance to burn of a rigidly-dried $2CO+O_2$ mixture. Using a spark across a 1/100-in. gap from a 1-in. Marconi induction coil with a current of six volts in the primary circuit, the following results were obtained:—

[21] See also Brewer, *Proc. Nat. Acad. Sci.*, 13 (1927), p. 689.
[22] *loc. cit.*

INFLUENCE OF INITIAL PRESSURE ON THE IGNITABILITY OF A DRY $2CO + O_2$ MIXTURE (*Bone and Fraser*).

Initial Pressure Atmospheres.	Result.	Percentage Combustion.
1·0	Could not be ignited.	—
1·5		—
3	Fired after many attempts	90·1
5·0		93·4
10·7	Always fired at first attempt.	99·1
19·0		99·3

Such results suggest that at high initial pressures the two gases will readily combine without the intervention of steam at all.

The Flame Spectra of Carbonic Oxide, Hydrogen and Water Gas. No observant person familiar with the flames of carbonic oxide and hydrogen can fail to be impressed by the striking contrast between them. Judged by the eye, the beautiful lambent blue flame of carbonic oxide in air is quite different from the hardly visible "sharp" flame of hydrogen. It is also well known that the flame of "water-gas" which chiefly consists of nearly equal volumes of carbonic oxide and hydrogen resembles that of hydrogen, without any of the characteristic blue colour of a carbonic oxide flame.

In the years 1923-5 F. R. Weston, working under the joint supervision of W. A. Bone and A. Fowler, undertook a spectroscopic analysis of such flames because it was felt that such evidence was needed for the further elucidation of the subject. Many valuable spectrograms were obtained, the outstanding facts concerning which may be summarised as follows:[23]—

(1) The flame spectrum of pure undried carbonic oxide burning in air or oxygen at atmospheric pressure consists of three distinct parts, namely, (*a*) a continuous spectrum extending from about 5,500 A.U. in the visible certainly up to 2,200 A.U. and possibly even farther in the ultra-violet region, and for the most part superposed upon (*b*) an ill-defined band spectrum, and (*c*) the characteristic ultra-violet bands of water vapour and especially a prominent group in the region 3,200 to 3,060 A.U. Both (*a*) and (*b*) are associated with the characteristic colour and actinic properties of the flame.

(2) Enrichment of the supporting atmosphere by oxygen much intensifies the continuous part (*a*) of the spectrum; also, drying

[23] *Proc. Roy. Soc. A*, 109 (1925), p. 177, also p. 523.

the gases (*i.e.*, the carbonic oxide and the oxygen) almost obliterates the "steam lines" without diminishing the intensity of the continuous spectrum.

(3) The gradual addition of hydrogen to a carbonic oxide flame causes the banded and continuous peak of the spectrum rapidly to disappear until with an equimolecular (water-gas) mixture only vestiges of them remain, leaving only "steam lines" recognisable. The addition of steam to the burning gas has much the same effect as hydrogen though on the whole less marked.

It seemed difficult to explain the foregoing facts except on the supposition that carbonic oxide burns in two different ways, which ordinarily occurs simultaneously, namely, (1) in which steam does not function chemically, and (2) in which it does so function. In (1) direct interactions occur between carbonic oxide and oxygen, exciting radiations which give rise to the continuous and banded parts of the spectrum and to the characteristic blue colour of the flame and in (2) interactions occur between carbonic oxide and steam, which originate the steam lines in the spectrum.

It should be also mentioned that W. E. Garner and C. H. Johnson[24] have shown that the presence of hydrogen or a hydrogen containing substance in the explosion of $2CO+O_2$ mixtures has a marked effect in reducing the emission of radiation in the infra-red. Thus, whereas the loss of radiant energy from the explosion of a well-dried mixture is nearly the equivalent of 10 per cent. of the total chemical energy set free, with 1·9 per cent. of water vapour present in the mixture the fraction of the chemical energy emitted as radiation falls to one-quarter of this value.

Summary. We think that, from the new evidence which has emerged from recent work, the presence of steam is not essential to the ignition and explosion of carbonic oxide and oxygen mixtures, as was formerly supposed.

Secondly, the spectrographic evidence shows undoubtedly that when *un dried* carbon monoxide burns in a flame both direct ($CO-O_2$) and indirect ($CO-OH_2$) oxidations proceed simultaneously and independently. The presence of hydrogen and steam undoubtedly favours the indirect oxidation.

It is probable that some degree of ionisation of one (or both) of the reacting gases is a necessary precedent to their combustion. Several agencies may bring about the needed activation. Steam, besides

[24] *Phil. Mag.* (1927), p. 97; (1928), p. 301. *Trans. Chem. Soc.*, 1928, p. 280.

acting chemically as it undoubtedly does, when present in sufficient concentration, may promote ionisation, possibly by condensing upon free electrons, thereby hindering their re-combination with positive ions and so prolonging and maintaining the reactivity of the system. Striking support to such a view is forthcoming from recent work of Finch and Hodge[25] (working with a direct current discharge), who find *inter alia* that in regions of sufficiently intense ionisation the presence of water has no accelerating influence on the combustion.

THE COMBUSTION OF HYDROCARBONS

Early Ideas. Throughout the greater part of last century it was generally accepted as an article of faith amongst chemists that the hydrogen, being (as was supposed) so much the more combustible of the elements of a hydrocarbon, is preferentially burnt when there is defect of oxygen. It is difficult now to see what experimental proof or basis there could have been for such a doctrine, for it was contradicted both by Dalton's experiments and those of Kersten.

In 1891, however, it was rediscovered in H. B. Dixon's laboratory that an equimolecular mixture of ethylene and oxygen yields on detonation almost exactly twice its own volume of carbonic oxide and hydrogen, in accordance with the empirical equation.

$$C_2H_4 + O_2 = 2CO + 2H_2$$

Simultaneously also Smithells and Ingle discovered large quantities of hydrogen and carbonic oxide in the inter-conal gases of hydrocarbon flames. These facts revived the idea of Kersten (1861) that "before any part of the hydrogen of a hydrocarbon is burnt, all the carbon is burnt to carbonic oxide, and the excess of oxygen (if any) divided itself between the carbonic oxide and hydrogen."

The idea, which ultimately furnished a solution of the problem, had been put forward by H. E. Armstrong in 1880. His conception was that the initial stage of the oxidation of a hydrocarbon might involve the transient formation of an unstable "oxygenated" molecule which, according to circumstances, would decompose more or less rapidly under the influence of heat.

The Hydroxylation Theory. An exhaustive series of researches which left no question as to the correctness of such a view was carried out by W. A. Bone and collaborators chiefly during the years 1900-1906, and also at intervals subsequently.[26] Some

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[25] *Nature*, October, 1927.

[26] *Trans. Chem. Soc.* 81 (1902), 535; 83 (1903), 1074; 85 (1904), 693 and 1637, 87 (1905), 910 and 1232; 89 (1906), 652, 660, 939 and 1614. *Phil. Trans. A* 215 (1915), p. 275.

hundreds of experiments were made upon the combustion of the hydrocarbons methane, ethane, propane, *n* and *iso*-butanes, the corresponding olefines (*i.e.*, ethylene and homologues) and acetylene, each in admixture with varying proportions of oxygen, and under all conditions from slow combustion at 300 to 400°C. through ordinary flame reactions, up to detonation and including high-pressure explosions. In the "slow combustion" experiments a number of "intermediate" products (chiefly aldehydes) were isolated, whilst the products obtained when the hydrocarbons were exploded with defect of oxygen were shown to be substantially those resulting from the thermal decomposition of alcohols and aldehydes.

As the outcome of these experiments it was concluded that (1) the slow oxidation of such hydrocarbons as methane, ethane and ethylene involve essentially successive hydroxylation stages with evolution of heat accompanied by (according to circumstances) the thermal decomposition of unstable "hydroxylated" molecules into simpler products, which may subsequently undergo further oxidation in like manner, and (2) although the same sequence of changes may not be reproduced exactly in flames the immediate result of the initial encounter between hydrocarbons and oxygen is probably much the same, in the two cases, namely, the formation of a "hydroxylated" or "oxygenated" molecule.

Considerable attention has recently been focussed on this aspect of the subject because of its importance in regard to the subject of "knock" in petrol-air engines (see next section); for it has been demonstrated that the phenomenon referred to depends upon the nature of the pre-flame slow oxidation of the hydrocarbon fuel concerned. Callendar and his collaborators,[27] and also Egerton and Gates[28] have shown that alkyl peroxides may be detected among the products of primary oxidation of those fuels which give rise to knock; also, that it is the rapid decomposition of such peroxides by "anti-knocks" which remedies the defect. From such observations it has also been argued that the initial oxidation of a hydrocarbon probably involves the formation of an alkyl peroxide by the direct incorporation of oxygen molecule as a whole after direct collision, such peroxide subsequently giving rise to aldehydes and water as decomposition products.[29] It is not possible here to detail the objections to such a view and, while not denying the

[27] *Engineering*, 123 (1927), p. 147, 182 and 210.
[28] *J. Inst. Pet. Tech.* 13 (1927), p. 244.
[29] See Mardles. *Trans. Chem. Soc.*, 1928, p. 872.

possibility of some small "peroxide" formation occurring during the compression stroke of a petrol-air engine, and thus causing "knock" we think that, judging from all the evidence so far available, the process for the most part is essentially one of "hydroxylation" and not "peroxidation.[30] "The two views are, however, not mutually exclusive, and may perhaps be supplementary; for only a very rash or dogmatic person would nowadays assert that every collision between hydrocarbon and oxygen molecules (or oxygen atoms) must always have precisely the same product as regards the particular 'oxygenated' molecule initially produced."[31]

SECTION III. EXPLOSIVE COMBUSTION

IGNITION TEMPERATURES

Chemical change may be determined in a gaseous explosive mixture at a much lower temperature than is required to develop flame in it. In such circumstances the rate of combustion is too slow to allow of any appreciable accumulation of heat in the system; but if the temperature be raised, the rate of combination is increased until at length a point is reached when the rate at which heat is dissipated from the system is more than counterbalanced by the rate at which it is developed by the interaction of the gases. The reaction thus becomes self-propellant; temperature continues to rise until ignition occurs and flame appears. The temperature at which such self-propellant combustion is established is usually termed the "ignition temperature" or "ignition point," but it is not a well-defined physical constant, being largely dependent on such factors as (*a*) the method of heating and (*b*) the nature of the environment. It is clear also that it does not correspond with the actual appearance of flame in the mixture; indeed, there is often a definite "pre-flame period, "during which the reaction is self-propellant.

No less than twelve different methods have been employed in the experimental determination of ignition temperatures; it is only possible here to mention a few of those used in more recent researches.

Concentric Tube Method. In 1909, Dixon and Coward[32] introduced

[30] Support for this view has recently been forthcoming from a paper by M. Stanislas Landa. *C.R.* 186 (1928), p. 589.

[31] Quotation from Bone & Townend's "Flame and Combustion in Gases," p. 377.

[32] *Trans. Chem Soc.* 98 (1909), p. 514.

their well-known "concentric-tube" method in which the combustible gas and air (or oxygen) were separately heated to the temperature of the enclosure before being allowed to mix, thus eliminating the influence of heated surfaces in promoting pre-flame combustion.

The "concentric-tube" apparatus has been considerably improved in recent years so that it is now possible (*a*) to study the influence on the "ignition point" of varying the pressure of the gases, and (*b*) to measure the "pre-flame" time lag. The following are representative of Dixon's recent determinations.[33]

INFLUENCE OF PRESSURE ON IGNITION TEMPERATURES (DIXON)

Ignition Temperatures in °C. of Hydrogen at Different Pressures

(*a*) *In Air.*

Lag.	75 mm.	100 mm.	200 mm.	400 mm.	600 mm.	760 mm.	1000 mm.	2 Atmospheres	3 Atmospheres	5 Atmospheres	7 Atmospheres
0·5 sec. ...	502°	515°	553°	594°	620°	630°	632°	628°	624°	618°	611°
5 secs. ...	—	—	541°	572°	585°	588°	592°	591°	591°	590°	589°
15 secs. ...	—	—	—	563°	570°	572°	573°	572°	567°	565°	563°

(*b*) *In Oxygen.*

Lag.	75 mm.	100 mm.	150 mm.	200 mm.	400 mm.	760 mm.	3 Atms.
0·5 sec. ...	500°	512°	533°	550°	591°	625°	618°
5 secs. ...	—	—	—	539°	566°	588°	565°
10 secs. ...	—	—	—	536°	561°	575°	546°

Ignition Temperatures in °C. of Methane at Different Pressures.

(*a*) *In Air.*

Lag.	100 mm.	200 mm.	400 mm.	600 mm.	760 mm.	1520 mm.	3 Atmospheres.	5 Atmospheres.	7 Atmospheres.
0·6 sec. ...	815°	788°	765°	753°	746°	722°	705°	675°	653°
5 secs. ...	—	697°	683°	679°	677°	666°	—	—	—
10 secs. ...	—	697°	664°	659°	657°	—	—	—	—

(*b*) *In Oxygen.*

Lag.	75 mm.	100 mm.	200 mm.	400 mm.	600 mm.	760 mm.
0·5 sec. ...	727°	728°	732°	720°	696°	670°
5 secs. ...	—	642°	633°	625°	621°	619°
10 secs. ...	—	633°	621°	611°	604°	602°

It will be observed that in the case of hydrogen there is a pressure (about 1,000 mm.) at which the ignition point is highest. On each side of this crucial pressure the ignition points fall. In the case of methane a similar crucial pressure occurs, but being below 100 mm. it is almost too low to be measurable.

It should be mentioned here that the term "ignition point" or "ignition temperature" refers strictly to a particular mixture of combustible gas and air (or oxygen) and varies considerably with

[33] *Trans. Faraday Soc.* 22 (1926), p. 267.

change of composition of the mixture. In the concentric tube method therefore it would seem probable that the "ignition point" appertains to a small range of the more readily ignitable mixtures.

Recently Dixon[34] has discovered that the presence of a trace of nitric oxide in the gases has a remarkable influence in lowering ignition temperatures. In the case of methane and air the presence of 0·005 per cent. of the impurity lowers the ignition temperature by 50°C.; further addition above this percentage, however, slowly raises the ignition temperature.

Method of using a Heated Vessel. The method of passing an explosive mixture into an evacuated vessel heated to a known temperature is frequently employed although it suffers from the inherent defect of surface action. It was originally employed by Mallard and Le Chatelier,[35] later by Taffanel and Le Floch,[36] and more recently by Mason and Wheeler.[37] The last-named investigators have determined the "relative ignitabilities" of mixtures of various paraffin hydrocarbons with air at atmospheric pressure, expressed in each case as the lowest temperature to which an enclosure need be heated in order to inflame the mixture passed into it.[39] Thus, in the case of methane-air mixtures the following figures have been found:—

Per cent. Methane	3·0	5·85	7·0	8·0	9·0	10·0	12·0	13·0
Temperature °C. of enclosure required for ignition ...	700°	695°	698°	701°	707°	713°	726°	732°

Ignition by Adiabatic Compression. During the years 1906-1907, H. S. Falk[38] endeavoured to determine the ignition temperatures of various gaseous explosive mixtures by compressing them in a steel cylinder by means of a steel piston driven by a falling weight, the temperatures being calculated by means of the formala

$$\frac{T_2}{T_1} = \left[\frac{V_1}{V_2}\right]^{\gamma-1}$$

In carrying out his experiments, however, he made some assumptions which later were shown by Dixon to be erroneous. In some new experiments carried out by means of this method Dixon and

[34] Private communication.

[35] *C.R.* 91 (1880), p. 825.

[36] *C.R.* 156 (1913), p. 1544; 157 (1913), p. 469.

[37] *Trans. Chem. Soc.* 121 (1922), p. 2079; 125 (1924), p. 1869.

[38] *Trans. Chem. Soc.* 121 (1922), p. 2079; 125 (1924), p. 1869.

[39] *Journ. Amer. Chem. Soc.* 28 (1906), 1517; 29 (1907), p. 1536.

Crofts found the following results in the case of diluted electrolytic gas mixtures.

Electrolytic Gas, $2H_2 + O_2 = 526°C$.					
$+xH_2$	°C.	$+xN_2$	°C.	$+xO_2$	°C.
$x=1$	544°	$x=1$	537°	$x=1$	511°
$x=2$	561°	$x=2$	549°	$x=7$	478°
$x=4$	602°	$x=4$	571°	$x=14$	472°
$x=8$	676°	$x=8$	615°	—	—
$(526+18x)°$		$(526+11x)°$			

The lowering effect of excess oxygen as compared with hydrogen and nitrogen is of great interest to chemists and its meaning can only be conjectured. Dixon and Crofts suggested the possible formation of some active polymeride of oxygen under the experimental conditions; on the other hand, it is probable that ignition is not altogether a thermal phenomenon, a matter which will be discussed later.

In a new apparatus Dixon has recently found the following figures:

$2H_2+O_2$	521°	CH_4+3O_2	340°
$2H_2+3O_2$	501°	CH_4+5O_2	345°
$2H_2+8O_2$	458°	CH_4+15O_2	377°
$2H_2+16O_2$	438°		

Tizard and Pye,[40] who have also studied the ignition of some hydrocarbon-air mixtures on adiabatic compression, point out that when there is appreciable delay between the end of compression and the occurrence of ignition it is exceedingly difficult to estimate "ignition points" owing to the temperature gradients occurring in the mixture. In their experiments the actual compression pressure was measured by means of an indicator, and it was found that this pressure might even fall before ignition occurred. They concluded that ignition occurred very locally and suggested that the true ignition temperature lay somewhere between those calculated from the measured and observed compression pressures respectively. Thus they found:

Mixture.	Minimum "average" temperature of compression to produce ignition.
Pentane-Air	316°
Hexane-Air	307°
Heptane-Air	298°
Octane-Air	297°

There remains the question about which we are still very much in the dark, namely, whether ignition can be regarded rightly as a thermal (temperature) process only, or to what extent (if any) "ionisation" is involved in it.

[40] *Phil. Mag.* 44 (1922), p. 791 ; (7), 1 (1926), p. 1094.

Ignition by Electrical Discharges. Although the practice of igniting explosive mixtures by electric discharges is so common nowadays the phenomena associated with it have been but little investigated up to the present. Indeed, there is still much difference of opinion as to whether, or how far, the igniting power of a given spark is due primarily to its temperature or to its ionising effect.

The problem was first systematically attacked by W. M. Thornton,[41] who pointed out that, whereas at that time it was being assumed generally that the processes of ignition and flame propagation are thermal throughout, recent work on the ionisation of gases had shown that a molecule can be ionised by corpuscular radiation, and that by the gain or loss of such corpuscles its "activity" can be profoundly modified. He showed experimentally that for given sparking conditions a certain "minimum igniting current" is required to ignite a given explosive mixture under known conditions, and argued that, if ignition was a purely thermal process, the igniting power of a spark in any given case should be proportional to the square of the current in the circuit; but, on the other hand, if it were primarily ionic, it would be proportional to the current, when this is unidirectional, but different for unidirectional and alternating currents of equal strengths. Taken as a whole, Thornton's experimental results seem to support this latter view. G. I. Finch and L. G. Cowen[42] have, however, pointed out that in Thornton's experiments, although the current flowing prior to opening the circuit might be known, in the case of direct current it could not be assumed to be equal to the maximum that passed in the discharge itself, also that with alternating currents additional complications would arise, in that the value of the maximum current would also depend upon the power factor of the circuit and frequency of the supply, as well as upon the actual moment at which the opening of the circuit began.

The discharges produced in electric bell signalling circuits, such as have been investigated by Morgan,[43] are low-tension discharges similar in character to those discussed above.

Besides Thornton, Morgan and Wheeler[44] have studied ignition by high-tension discharges produced by means of an induction coil or magneto across a fixed gap. This type of discharge is oscillatory

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[41] *Proc. Roy. Soc. A*, 90 (1914), pp. 272-297; 90 (1914), pp. 17-22; 92 (1915), pp. 9-22 and pp. 381-401.
[42] *Proc. Roy. Soc. A* 111 (1926), pp. 257-280.
[43] *J. Chem. Soc.*, Vol. 115 (1919), p. 94.
[44] *J. Chem. Soc.*, Vol. 119 (1921), p. 239.

and extremely complex. Morgan[45] and Patterson and Campbell[46] have shown that the igniting power of such a discharge depends solely on the energy associated with the first oscillation, and not on the total energy dissipated in the complete train of oscillations. In none of the experiments of the workers cited above was the rate of dissipation of energy constant, nor were the values of the maximum and main currents flowing determined. Another circumstance which must not be forgotten is that the region of a discharge, particularly when passing in a gas under normal pressure, is a zone of high temperature, and contains the vapour of the electrode materials; also in oscillatory discharges, intense pressure waves are set up in the surrounding gas. Thornton showed that the nature and condition of the electrode material had a considerable, and sometimes erratic, influence upon the experimental results obtained with his "break-sparks." It is, therefore, difficult to compare and interpret much of the published experimental work, because of the fact that the types of electric discharges used by the different investigators have involved the introduction of unknown factors (both electrical and otherwise) which have obscured the issues. In studying the electrical ignition of gases, the investigators referred to above were, however, primarily concerned with the examination of such conditions as arise in ignition either in internal combustion engines or in coal mines, and the types of electric discharges investigated were selected as closely reproducing those occurring in actual practice.

G. I. Finch and L. G. Cowen[47] have made a study of the slow combustion and ignition of electrolytic gas which has contributed materially towards elucidating the mechanism of ignition. These workers employed steady direct currents, special precautions being taken to ensure that the current passed in the discharge was perfectly uniform, and hence the rate of dissipation of energy constant. Steps were also taken to ensure that the non-electrical phenomena with which the electric discharge is ordinarily associated were either eliminated or reduced to a minimum. It was shown, *inter alia*, that the rate of combustion under the above conditions was directly proportional to the current and that a hyperbolic relationship existed between the gas pressure and the least igniting current, thus proving that the electrical ignition of electrolytic gas is determined solely by the attainment in some portion of the gas traversed by the discharge of a certain definite concentration of ions or electrically

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[45] "Principles of Electric Spark Ignition."
[46] *Proc. Phys. Soc.* (1919), p. 177.
[47] *loc cit* and *Proc. Roy. Soc. A*, Vol. 116 (1927), p. 529.

charged particles. Another significant fact observed by these workers was that the rate of flame propagation in electrolytic gas along the path of the electric discharge was at least ten times greater than elsewhere.

Thus there seems to be but little doubt that electrical ignition is primarily an ionic process, and that the rôle of temperature is merely that of facilitating the supply of ions necessary for combustion.

The well-known fact that excess oxygen lowers the ignition temperature of hydrogen and the recent important discovery by H. B. Dixon[48] that traces of nitric oxide lowers ignition temperatures as determined by the concentric-tube method, to a remarkable extent, are facts which seem strongly to support the view that ignition (as also combustion which may be regarded as a series of successive ignitions) is fundamentally an electrical process, determined by the setting up of suitable concentrations of ions.

LIMITS OF INFLAMMABILITY

An inflammable or explosive mixture may be defined as one through which flame can be propagated independently of, and away from, the original source of ignition.

In the case of mixtures of any particular combustible gas and air (or oxygen) there are, under given physical conditions, certain limits of composition within, but not outside of which, self-propagation of flame will take place after ignition has once been effected. These limits, defined in terms of the percentage of the combustible gas present, are usually referred to as the "lower" and "upper" limits of inflammability, respectively, of the gas under given conditions. For any particular gas, however, they vary with the position of the source of ignition, since the progress of flame may be assisted or retarded by convection currents, according as it has to pass in an upward or downward direction. Thus, for example, for methane-air mixtures, at atmospheric temperature and pressure, the limits for different propagation directions are as follows:—

	Direction of propagation.		
	Upward.	Horizontal.	Downward.
Lower limit	5·35	5·40	5·95
Upper limit	14·85	13·95	13·35

In the following table are given the limits of the principal gases and vapours determined by A. G. White[49] for upward propagation of flame in a glass tube 7·5 cm. in diameter.

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[48] Private communication.

[49] *Trans. Chem. Soc.* 121, (1922), p 1244; p. 1688; p. 256; 125 (1924), p. 2387; 127 (1925), p. 48; p 672.

	Lower. Upper.		Lower. Upper.
Hydrogen	4·15 to 75·0	Ethyl ether	1·71 to 48·0
Carbon monoxide	12·8 to 72·0	Acetone	2·89 to 12·95
Hydrogen sulphide	4·30 to 45·5	Benzene	1·41 to 7·45
Methane	5·35 to 14·85	Toluene	1·27 to 6·75
Ethane	3·12 to 14·95	Methyl alcohol	7·05 to 36·5
Pentane	1·42 to 8·0	Ethyl alcohol	3·56 to 18·0
Ethylene	3·02 to 34·0	Carbon disulphide	1·06 to 56·0
Propylene	2·18 to 9·7		
Butylene	1·70 to 9·0		
Acetylene	2·60 to 80·5		

White has also found that in the case of certain vapour-air mixtures it is possible under favourable conditions to propagate a "cool flame" of incomplete combustion. With mixtures of ethyl ether and air there are two ranges of inflammability for horizontal propagation of flame (1·88 to 9·45 and 19·0 to 34·0 per cent.), separated by a range which will not propagate flame, the higher of the two ranges relating to the "cool flame." In this connection it may also be mentioned that the ignition point for a "cool flame" ("sub-ignition temperature") is somewhat below that for the initiation of the normal flame.

Influence of Temperature. As might be expected, the effect of increase of temperature is generally to widen the limits. Thus in the case of methane, Mason and Wheeler gave the following figures:[50]—

Initial temperature °C.	Per cent. Methane in limit mixture for Downward Flame Propagation. Lower.	Upper.
20°	6·0	13·40
100°	5·45	13·50
200°	5·05	13·85
500°	3·65	15·35
700°	3·25	18·75

Influence of Pressure. Recently Bone, Newitt and Smith[51] have given an account of an investigation into the effects of high initial pressure upon the ranges of explosibility of various gas-air mixtures with results as follows:—

Gas.	10 Atmospheres.	50 Atmospheres.	125 Atmospheres.
Hydrogen-air	10·2 to 68·5	10·0 to 73·3	9·9 to 74·8
Carbon monoxide-air	17·8 to 62·8	20·6 to 56·8	20·7 to 51·6
Methane-air	6·0 to 17·1	5·4 to 29·0	5·7 to 45·5

It would thus seem that whereas the range for carbon monoxide-air mixtures is considerably narrowed at both ends, the range of

[50] *Trans. Chem. Soc.* 113 (1918), p. 45.
[51] *Proc. Roy. Soc. A*, 117 (1928), p. 553.

hydrogen-air and of methane-air mixtures are both widened at the higher limit as the initial pressure increases.

It may be mentioned that a review of all the experimental researches into limits of inflammability has been published recently by Coward and Jones, U.S. Bureau of Mines Bulletin, No. 279 (1928).

PROPAGATION OF FLAME

Slow Movement of Flame. In 1857 Bunsen made the first measurements recorded of the speeds at which flames are propagated through gaseous explosive mixtures. His method consisted of lighting an explosive mixture issuing at a known velocity from a tube through an orifice in a metal plate; its velocity was then gradually reduced until the flame just struck back through the orifice and ignited the mixture in the tube beyond it. In this way he found a velocity of one metre per sec. for a $2CO+O_2$ mixture and 34 metres per sec. for electrolytic gas ($2H_2+O_2$) at atmospheric temperature and pressure. In 1881, however, Mallard and Le Chatelier took the matter very much further, showing that gaseous explosions pass through well-defined stages, commencing with a comparatively slow flame propagation which soon is accelerated, and culminating in the phase of maximum high speed and intensity known as "detonation," discovered independently by Berthelot and Vielle in the same year.

Mallard and Le Chatelier used a variety of experimental methods but developed most successfully the photographic one, which to-day has reached a very high state of perfection and is now almost universally employed for such work. By such means the movement of flame through an explosive mixture, usually along a horizontal glass tube, is recorded on a sensitive film wound round a rotating cylinder (in the early work a falling plate was employed).

Mallard and Le Chatelier employed explosive mixtures of carbon disulphide and oxygen (or nitric oxide) because of the actinic flames produced and found the behaviour of such mixtures to differ according as they were ignited at or near (*a*) the open, or (*b*) the closed end of a tube. In the case of (*a*) it was always observed that the flame proceeded for a certain distance along the tube at a practically uniform velocity, which was regarded as the true rate of propagation by conduction. This uniform velocity was succeeded by an "oscillatory period," the flame swinging backwards and forwards with increasing amplitudes, and finally either dying out altogether or in certain cases giving rise to "detonation." When, however, the mixtures were ignited near the closed end of the tube, the

forward movement of the flame was continuously accelerated until finally "detonation" was set up.

The researches of R. V. Wheeler[52] and his collaborators since 1914 under the auspices of the Safety in Mines Committee have greatly extended our knowledge of the initial slow uniform movement. Mason and Wheeler considered that it should be regarded simply as a particular phase in the propagation of flame that occurs when

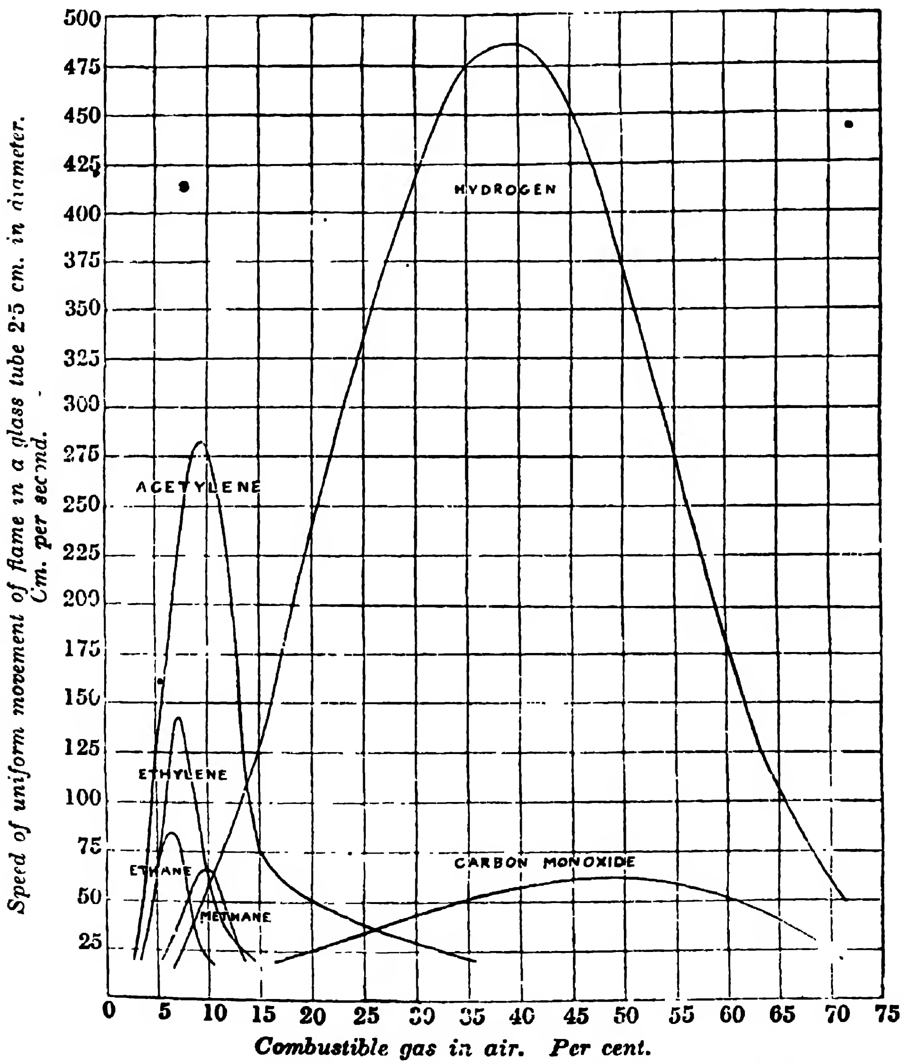

Fig. 3. Comparison of speeds of "Uniform movement" of mixtures of various combustible gases with air. (Chapman.)

[52] *Trans. Chem. Soc.* 105 (1914), p. 2606; 109 (1916), p. 83; 111 (1917), p. 267, p. 841, p. 1044; 113 (1918), p. 656; 115 (1919), p. 36, p. 578, p. 1446; 117 (1920), p. 36, p. 48, p. 1227; 119 (1921), p. 1677.

ignition is effected (in a quiescent mixture) at the open end of a straight horizontal tube closed at the other end, and not as resulting from a particular mode of heat transference. Such factors as tube diameter, direction of propagation, etc., have been extensively studied. In Fig. 3 a series of curves is shown which summarises in a convenient manner the speeds of uniform movement obtained in Wheeler's laboratories for mixtures of air with various combustible gases.

In 1922 Payman and Wheeler[53] propounded a new "law of flame speeds" for complex combustible gaseous mixtures, *e.g.*, coal-gas and air, on the supposition that in such cases the observed flame speed is caused by the oxygen or combustible gas (whichever of the two is in defect) dividing itself during the combustion so as to form a series of explosive mixtures (of each single component combustible gas with oxygen), giving the same flame speed. In the course of an investigation which drew attention to a number of exceptions to this so-called "law" Bone, Fraser and Winter[54] showed that it is to be doubted whether it is possible rigidly to maintain (1) that all quiescent explosive mixtures necessarily develop an initial *uniform* flame movement, or (2) that even when a uniform velocity is initially set up in such circumstances, its velocity is necessarily always the same.

Detonation. The phenomenon of detonation or "l'onde explosive," as it was originally known, was discovered independently by Berthelot and Vielle and by Mallard and Le Chatelier in 1881. It is set up when a sufficiently explosive mixture is ignited by means of a detonator (*e.g.*, a fulminate charge) or under circumstances such that an advancing flame is exposed to the repeated effects of reflected compression waves.

Much of our knowledge concerning the setting up of detonation in the last-named circumstance is due to the photographic investigations of H. B. Dixon and his collaborators. In Fig. 4 is shown one of Dixon's photographs of the development of an explosion in a CS_2+5O_2 mixture. This photograph is analysed in Fig. 5. The igniting spark in starting the explosion at O sends out invisible compression waves in both directions along the tube; these traverse the unburnt gases in advance of the flame with the velocity of sound, as indicated by the dotted lines OM, ON in the diagram. The flame itself, travelling at first more slowly than the compression waves, traces the curves OA and OB. The compression wave ON,

[53] *Trans. Chem. Soc.* 121 (1922), p. 363.
[54] *Proc. Roy. Soc. A*, 114 (1927), p. 402.

on reaching the closed end of the tube, is reflected back again as NC, and, on meeting the flame (which is still travelling in the direction OA), retards it, and passes thence through the hot and still burning gases as the visible wave CD. An instant later it overtakes, at D, the front of the flame travelling in the direction OB, thereby accelerating it, and increasing its luminosity in consequence of the quickened combustion. The flame then continues to move forward

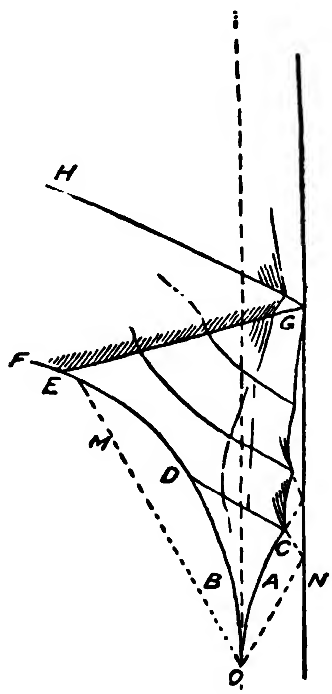

Fig. 4. Development of an Explosion in a $CS_2 + 5O_2$ mixture.

Fig. 5. Analysis of same.

(From "Flame and Combustion in Gases.")
(By kind permission.)

from D with rapidly accelerated velocity until "detonation" is finally set up at the point E, near where the flame catches up with the compression wave OM. Indeed, it is the forward "kick" received by the already accelerated flame front on its overtaking the compression wave OM which finally determines "detonation." At the instant when "detonation" is set up the flame attains its final constant velocity, and the combustion and luminosity their maximum intensities; simultaneously, a strongly luminous wave of compression EG (called the "retonation wave") is sent backwards

through the still burning gases, which on reaching the near end of the tube is reflected back as HG. The "detonation" wave EF passes onwards through the mixture with its characteristic high velocity and intense luminosity.

The following speeds have been given by Le Chatelier for the velocities of the various waves set up in a $C_2H_2+O_2$ mixture.,

	Metres per second.
Detonation wave	2,990
Retonation wave	2,300
Reflected wave	2,250
Collision wave	2,050

When once established, the velocity of detonation (usually about 2,000 to 3,000 metres per second) is constant and within wide limits unaffected by the material and diameter of tube employed, being solely dependent on the nature of the explosive mixture and on its temperature and pressure.

Berthelot and Dixon both likened the explosion wave to that of sound travelling with a velocity determined by the physical conditions of the hot explosion gases. It has since been shown, however, to be more in conformity with a "shock wave" (*i.e.*, a wave in which a steep pressure change is propagated through the gaseous medium) the pressure in which is maintained by the adiabatic combustion of the explosive mixture; and in accordance with such a view equations have been developed independently by Chapman[55] and by Jouguet,[56] which agree closely with experimental results.

Recent photographic investigations on the setting up of detonation have been made by Egerton and Gates,[57] Laffitte,[58] Payman,[59] and Campbell and Woodhead.[60] Some beautiful photographic records of detonation phenomena have also been obtained recently by F. R. Fraser, working in W. A. Bone's laboratories at the Imperial College, London.

Explosions in Closed Vessels

Early Experiments. Up to the end of last century the most important work upon gaseous explosions in closed vessels had been the classical researches of the French chemists, Berthelot and Vieille and Mallard and Le Chatelier, who were investigating the purely scientific aspects of the problem, and of Dugald Clerk in this country,

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[55] *Phil. Mag.* 47 (1899), p. 90.
[56] *Jour. de Math.*, 1905 and 1906.
[57] *Proc. Roy. Soc.* 114 (1927), p. 137; 116 (1927), p. 516.
[58] *C.R.* 176 (1923), p. 1392; 177 (1923), p. 178; 179 (1924), p. 1394; 183 (1926), p. 284; 186 (1928), p. 951.
[59] *Proc. Roy. Soc. A*, August, 1928.
[60] *Trans. Chem. Soc.*, 1926, p. 3010.

who was then working on the development of the gas engine. The main outcome of all three researches was the confirmation of the earlier observations of both Hirn (1861) and Bunsen (1867) that the pressure developed in a gaseous explosion is considerably less than that which would result if (*a*) there were no heat loss, (*b*) combustion were complete, and (*c*) specific heats were independent of temperature.

Whereas Hirn had considered that such result was accounted for entirely by heat loss due to conduction and Bunsen had attributed it to combustion in stages (per saltum), the French investigators rightly assigned it in the main to the marked increase in molecular heat capacity with temperature of steam and carbon dioxide. Clerk, who at that time considered the theory of increased heat capacity with temperature to be erroneous, put forward another explanation, namely, that combustion may not be completed within the period required for the attainment of maximum pressure, with the consequent occurrence of "after burning."

In the light of modern knowledge, the factors which may affect the maximum pressure attained in a gaseous explosion are as follows:—

(1) Increase of molecular heat capacity with temperature.
(2) The occurrence of dissociation.
(3) Heat loss by conduction and convection.
(4) Loss of "energy" by direct radiation.
(5) Any after-burning.

(1) is by far the most important; (2) is mainly dependent on the temperature attained, and in certain cases may be appreciable; and (3) and (4) depend almost entirely on the time of attainment of maximum pressure and in fast explosions are probably small. (5) may be operative in certain cases but it may be questioned whether it is generally so.

Recent Researches. Difficulty was always experienced in the early experiments in securing pressure-time records quite free from vibration effect due to the comparatively long natural time-period of the controlling spring of the recording monameter. In 1905, Sir Joseph Petavel designed a recording manometer for working at high initial pressures in which an exceedingly strong tubular steel spring was employed, the very small linear movement produced in an explosion being magnified by converting it into the angular movement of a mirror which reflected a beam of light on to a rotating film. The same principle was applied by Pier working in Nernst's laboratory for work at ordinary pressure by replacing the tubular

spring with a strong disc of special steel. Thus to-day explosion pressures may be measured with a high degree of accuracy, any inertia effects produced in the recording manometer being reduced to a minimum.

One of the most important objects which has stimulated researches on gaseous explosions during the last twenty years has been that of determining the specific heats of gases and the degrees of dissociation of steam and carbon dioxide respectively at the maximum temperatures attained. At very high temperatures the measurement of the pressures developed in explosions affords the only available method for such work, and although certain allowances have to be made for cooling losses, the results obtained have been found to agree well with those deduced theoretically from a knowledge of such values at low temperatures. Excepting the work on gaseous explosions at high initial pressures carried out by Bone and collaborators at the Imperial College, London, the results of which, as bearing on dissociation and specific heats, are now being published,[61] the principal researches have been those of Langen, and later of Pier,[62] Bjerrum,[63] Budde[64] and Siegel,[65] all working in Nernst's laboratory, and also more recently of Fenning and Tizard.[66]

Fenning's Experiments. Fenning, working at the National Physical Laboratory, has studied the explosion of various combustible gases and vapours with air or oxygen at initial pressures up to 10 atmospheres and at initial temperatures up to 400°C.[67] He has found that the effect of raising the initial temperature of an explosive mixture is to diminish the time required for the attainment of maximum pressure; no general conclusion, however, can be drawn from his results as to the influence of raising the initial pressure.

In the case of the explosion of vapour-air mixtures his results are of particular importance as bearing upon the subject of "knock," to which we shall refer later. At an initial temperature of 100°C. and an initial pressure of 93 lb. per sq. in., *rich* mixtures of either benzene, hexane or petrol gave rise to "knock." On raising the initial temperature to 300°C. the "knock" was suppressed in the case of rich

[61] *Proc. Roy. Soc. A*, 119 (1928), p. 464.
[62] *Z. Elecktro. Chem.* 15 (1909), p. 536; 16 (1910), p. 897. *Zeit. Phys. Chem.* 62 (1908), p 385; 66 (1909), p 759.
[63] *Z. Elecktro. Chem.* 17 (1911), p. 731; 18 (1912), p. 101; *Zeit. Phys. Chem.* 79 (1912), p. 513 and 537; 81 (1913), p. 281.
[64] *Zeit. Anorg Chem.* 78 (1912), p. 159.
[65] *Zeit. Phys. Chem.* 87 (1914), p. 641.
[66] *Proc. Roy. Soc. A* 115 (1927), p. 318.
[67] *Rep. and Mem. Aero Research Committee*, No. 902 (1924), No. 979 (1925), also *Phil. Trans.* A 225,(1926), p. 231.

benzene-air mixtures, but in the case of rich hexane or petrol-air mixtures it still persisted. With theoretical air-petrol and air-hexane mixtures, raising the initial temperature led to "knock," the intensity of which increased with temperature. With the theoretical air-benzene mixture there was no indication of the production of "knock" with increase of initial temperature.

Gaseous Explosions at High Pressures. Since 1919 the researches on gaseous explosions at high initial pressures started by W. A. Bone and collaborators at Leeds twenty years ago, have been considerably advanced at the Imperial College, London.[68] It is not possible to refer here to the various ramifications of the subject, but it may be said that, *inter alia*, the following influences will be operative in high-pressure explosions, namely:—

(1) Generally speaking, an increase in the density of the explosive medium, involving, as it does, a proportionate increase in the number of molecular collisions per second, would increase the absolute amount of chemical change in a given volume per second.

(2) The rate of heat losses would become relatively less.

(3) Effects of "dissociation" would diminish; though here it must be remembered that inasmuch as any increase in the maximum temperature would have an opposite effect, what is actually observed in any particular case will be the resultant of these two effects.

(4) An increase in the density may effect both emission and absorption of radiant energy during an explosion.

In the main the effect of increasing initial pressure up to 200 atmospheres on explosions of theoretical H_2-air and CO-air, etc., mixtures has been studied. It has been found that under such conditions increase of initial pressure decreases the explosion time and only when nitrogen is present in juxtaposition with carbon monoxide does the reverse occur. In this case, high initial pressure considerably retards the attainment of maximum pressure; moreover, after the attainment of maximum pressure, an evolution of heat occurs far into the cooling period. This phenomenon has been explained on the supposition (1) that radiation emitted in a CO-oxygen explosion at high pressure is absorbed by the combustible gas, which is thereby "activated" so as to be capable of combining directly with oxygen, (2) that when nitrogen is present as a diluent, part of the radiation so emitted is intercepted and absorbed by the nitrogen (which is thereby activated), so that the rate of activation

[68] *Phil. Trans.* A. 215 (1915), p. 275; *Proc. Roy. Soc.* A, 103 (1923), p. 205; 105 (1924), p. 406; 108 (1925), p. 393; 110 (1926), p. 645; 115 (1927), p. 45; 116 (1927), p. 637; 117 (1928), p. 553; 119 (1928), p. 464.

of the CO molecules is retarded, thus producing the observed "lags" in the attainment of maximum pressure, which "lags" increase with the density of the medium, and (3) the nitrogen so "activated" either (*a*) reverts to the ordinary state during the "cooling period," liberating (as sensible heat) the equivalent of the radiant energy, which is absorbed during the "explosion period," or (*b*) where excess of oxygen is present, combines with it, forming nitric oxide. Confirmation of such explanation has been forthcoming from a spectroscopic examination of the emission from the explosion flames through specially fitted quartz windows. For further information the original papers should be consulted.

THE PROBLEM OF "KNOCK" IN PETROL-AIR ENGINES

Perhaps the most interesting problem in combustion during recent years has been that of "knock" in petrol-air engines. And it is of so great importance to the internal combustion engineer that much effort has been concentrated in its investigation, although to-day we are still without a complete understanding of it.

In order to increase the efficiency of the present-day petrol-air engine it is most important that the designer should be allowed to increase the usually employed compression ratio of 5 : 1, which if now exceeded results in the occurrence of "knock." The value of such an increase in compression ratio will be seen from the following table, in which efficiencies for various compression ratios are given calculated from the well-known thermodynamical formula

$$E = 1 - \left(\frac{1}{r}\right)^{\gamma - 1}$$

Compression Ratio.	Calculated Efficiency $\gamma = 1{\cdot}4$	Calculated Efficiency (Tizard & Pye).	Observed Efficiency (Tizard & Pye).
4 to 1	0·425	0·337	0·277
5 to 1	0·475	0·380	0·316
7 to 1	0·540	0·440	0·372

In the second column the values are calculated on the "ideal air" standard where $\gamma = 1{\cdot}4$, and in the third column Tizard and Pye's ideal efficiencies are given, their γ having been calculated in accord with Pier and Bjerrum's specific heat values. In a fourth column Tizard and Pye's observed efficiencies for a weak vapour-air mixture are shown; the difference between their calculated and observed values being in close agreement with the estimated heat loss.

When "knock" occurs, pressure in the cylinder is not built up smoothly. A fugitive and abnormally high pressure, accompanied by a sharp metallic ring, is developed instantaneously, the cylinder walls and piston receiving, as it were, a "hammer blow" instead of an effective thrust, with consequent loss of efficiency and strain on the working parts.

The phenomenon simulates detonation and is still attributed in some quarters to this cause. Unfortunately the conditions prevailing in an engine are far removed from those under which any detailed study of the setting up of detonation waves can be made experimentally. There are reasons, however, for doubting the likelihood of a true detonation wave being set up in such circumstances.

Thus Dixon, in 1920, found that it was exceedingly difficult to set up a detonation wave in a vapour-air mixture and only in the cases of alcohol and ether could it be propagated at all. Moreover, the setting up of a detonation wave is largely influenced by the repeated effects of reflected compression waves. These largely depend on the symmetry of the containing vessel, and ordinary engine cylinders are very irregular in shape. Also, a detonation wave is not usually established until the flame has travelled a certain distance, depending on circumstances, and an engine cylinder does not nearly allow of this. Again, from the practical point of view those who have experimented on the problem consider the effects of repeated *true* detonation waves would have a far more injurious effect on an engine cylinder than is usually found as the result of "knocking." For these reasons recent theories tend towards the belief that "knock" is connected with some form of spontaneous ignition of the unburnt charge, which has been compressed above its ignition point by the expansion of the already combined gases.

The tendency of fuels to "knock" is closely connected with their ignition temperatures. Thus, the higher paraffin hydrocarbons give rise to "knock" more easily than the lower ones, it being well known that the ignition temperature diminishes as the series is ascended. Moreover, Tizard and Pye have shown that when vapour-air mixtures are compressed to temperatures *above* their respective ignition temperatures there is a close connection between the temperature coefficient of the reaction velocity as shown by the observed "lags" and the tendency to "knock."

It is also agreed that in practice any factor which helps to reduce the temperature attained, either locally or generally, in the unburnt explosive medium will also reduce the tendency to "knock."

The tendency to "knock" is more marked in some fuels than in others. The members of the paraffin series and ether are among the worst offenders, but aromatic hydrocarbons and alcohol are comparatively free from the defect under ordinary conditions. Indeed, the marked tendency of petrol fuels to "knock" may be diminished by diluting them with benzol.

In 1922, Midgley announced the important discovery of "anti-knocks" or substances which, when added to liquid fuels in very small proportions, have the effect of suppressing their tendency to "knock," and such "anti-knocks" are now widely used in practice. The precise function of an "anti-knock" has naturally given rise to much speculation and there is little doubt that a true understanding of such function would contribute much to the elucidation of the whole problem.

It is clear that the effect of "anti-knocks" cannot be explained on purely thermal grounds for they are never present in sufficient quantity to have any appreciable influence in lowering the temperature of the gaseous reaction. Moreover, it has been shown that their presence has little influence on "flame velocities," "the setting up of detonation waves," or on "detonation velocities." Midgley ascribed the "knock" suppressing characteristics to the particular metallic or other atoms (iodine or nitrogen for example) present which, on thermal decomposition of the "anti-knock," acted as screens in selectively absorbing radiation and thereby reducing flame velocity.

Other workers have considered that "anti-knocks" may interfere with the degree of ionisation occurring in flames, but the experimental evidence on this point is of a contradictory nature. Recently Bennett[69] has studied the matter, arriving at the conclusion that "Although ionisation accompanies detonation, as it does all flame phenomena, there is no simple relationship between them. Ionisation does not appear to be either a cause or an effect of detonation but mainly a temperature effect." He also found the function of "anti-knocks," as increasing or decreasing ionisation, to be very variable.

Another explanation is that the action of (say) lead tetra-ethyl is associated with the liberation of fine particles of the free metal in a gaseous mixture which, functioning as catalysts, and themselves undergoing rapid oxidation, produce a large number of oxidation centres. In this way a homogeneous combustion throughout the

[69] *Trans. Fara. Soc* 23 (1927), p. 301.

gas mixture ahead of the flame front might occur, thereby suppressing "knock."

H. L. Callendar[70] has pointed out that vapourised hydrocarbons and particularly those of high molecular weight (whose ignition temperatures are lowest) will tend to condense on compression and to form minute liquid drops. Particularly would this be the case when the fuel is injected as a spray or when carbon particles are present, thus supplying nuclei for the initiation of condensation. Such freshly condensed drops would be in an active state and, absorbing oxygen, would become loci of chemical reaction and ultimately give rise to spontaneous ignition throughout the mass.

Recently Callendar and his collaborators[71] have found that those fuels which give rise to "knock" show a tendency to form explosive peroxides, and that this tendency is enhanced when the explosive medium contains liquid drops. It is suggested that in engine explosions "the amount of peroxide formed would not of itself be sufficient to cause the detonation observed, but act as a primer, causing simultaneous ignition of the drops. Metallic 'anti-knocks' act by reducing the peroxides as fast as they are formed, thus delaying the ignition of the drops."

Egerton and Gates [72] have also detected the presence of peroxides in the slow oxidation of the hydrocarbons concerned. The presence of "anti-knocks" decreases the reaction velocity of oxidation considerably and thereby raises the ignition temperature. In the opinion of these investigators the "peroxide" autocatalyses the normal course of oxidation and its removal therefore slows down the initial stages of combustion and thereby suppresses "knock."

From what is now known it would seem that "knock" is determined in any particular case by the rate of pre-flame combustion. It may be attributable to a spontaneous ignition of the mass of gas ahead of the flame as a whole, but seems more likely to be due to a "pseudo-detonation" (probably much less violent than true detonation), which may conceivably be propagated through an explosive medium in which the rate of pre-flame oxidation has already reached an advanced stage.[73]

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[70] *Rep. and Mem. Aero Research Committee*, No. 1013 (1926).
[71] *Engineering*, Feb. 4, 11 and 18 (1927).
[72] *J. Inst. Pet. Tech.* 13 (1927), p. 299.
[73] Quite recently Maxwell and Wheeler have obtained photographic records which indicate that in explosions where "knock" occurs a flame of incomplete combustion traverses the explosive medium and on reaching the walls of the vessel it becomes vibratory in character, and ultimately gives rise to a "compression" or "shock" wave, which passes back instantaneously through the partially burnt gases. (*J. Inst. Pet. Tech.* 14 (1928), p. 175. See also Duchene 186 (1928), p. 220.)

SECTION IV. CATALYTIC AND INCANDESCENT SURFACE COMBUSTION

It is necessary to distinguish between two possible conditions under which gaseous combustion may occur, namely, (1) *Homogeneously*—that is to say, equally throughout the system as a whole, at temperatures below the ignition point *slowly* and *without flame*, and at temperatures above the ignition point *rapidly* and *with flame*; and (2) *heterogeneously* or only in layers immediately in contact with a hot or incandescent surface (surface combustion).

Catalytic Combustion. It is now generally recognised in principle that all hot surfaces have an accelerating influence upon chemical change in gaseous systems. The subject as a whole is probably one of the most important in modern chemistry, and any general treatment of it would be quite beyond the scope of this article.[74] It may be indicated, however, that whilst ideas concerning the exact processes by which surfaces so function are still very much in the melting pot, it is agreed that the following are the essential factors in the phenomenon:—

(1) An activation of the reacting gases (or at least one of them) at the surface, resultant upon (2) an adsorption or occlusion of such gases (in some cases such "activation" may be considered as ionisation), and (3) the rate at which the activated gases may themselves combine or give rise to combination in the gases remote from the surface.

The subject has been studied fundamentally in its bearing upon combustion by W. A. Bone and collaborators during the past twenty-five years, and attention is specially directed to a series of papers recently published in the Proceedings of the Royal Society.[75] Bone's work commenced in 1900 with a systematic investigation, in conjunction with R. V. Wheeler, on the "Combination of Hydrogen and Oxygen in Contact with Hot Surfaces"[76] (published in 1906), in the course of which new facts and conclusions were established in many ways closely related to those developed independently ten years later by Irving Langmuir[77] from a rather different experimental basis.

[74] See "Catalysis in Theory and Practice." Rideal and Taylor (Macmillan, 1926).
[75] *Proc. Roy. Soc.* A 109 (1925), 459; 110 (1926), 16; 112 (1926), 474; 114 (1927), 169, also *Phil. Trans. Roy. Soc.* A 206 (1906), p. 1.
[76] Recent papers on this subject by Hinshelwood [*Proc. Roy. Soc.* A 118 (1928), p. 170; and 119 (1928), p. 591] should be consulted.
[77] See *Trans. Faraday Soc.* 17 (1922), p. 545.

G. I. Finch and J. C. Stimson[78] have extended recently the earlier observations of Hartley[79] in Bone's laboratories at the University of Leeds upon the electrical condition of surfaces during absorption of gases and their catalytic combustion and have obtained results which indicate that an ionisation both of the combustible gas and of the oxygen proceeds concurrently with the catalytic combustion over such surfaces.

Incandescent Surface Combustion. It may be recalled how Sir Humphry Davy in 1817 showed that a mixture of hydrogen and oxygen can combine at about 400°C. "without violence and without any light." He also set out to enquire whether "seeing that the temperatures of flames far exceed those at which solids become incandescent, a metallic wire can be maintained at incandescence by the combination of gases at its surface without actual flame," and made the discovery that a warm platinum wire introduced into a mixture of coal-gas and air rendered non-explosive by excess of the combustible immediately becomes red hot and continues so until nearly the whole of the oxygen has disappeared.

As an outcome of researches carried out during 1909-12, W. A. Bone and C. D. McCourt developed a new system of "incandescent surface combustion," in which a homogeneous explosive mixture of gas and air in proper proportions for complete combustion (or with air in slight excess thereof) was caused to burn without flame in contact with a granular incandescent solid. And, during recent years, a considerable advance has been made in the technical application of this catalytic process for various industrial heating operations.[80]

The advantages of such a system are: (1) the combustion is so greatly accelerated by the incandescent surface, and, if so desired, may be concentrated just where the heat is required; (2) the combustion is perfect with a minimum excess of air; (3) the attainment of very high temperatures is possible without the aid of elaborate "regenerative devices"; and (4) owing to the large amount of radiant energy developed, transmission of heat from the seat of combustion to the object to be heated is very rapid. When applied to steam raising thermal efficiencies as high as 92 to 93 per cent. of the *net* calorific value of the gas **burnt** have been recorded, and

[78] *Proc. Roy. Soc.* A 116 (1927), p. 379, A 120 (1928), p. 235.
[79] *Proc. Roy. Soc.* A 90 (1914), p. 61.
[80] *Proc. Amer. Gas Inst.* VI. (1911), p. 565; *Jour. Franklin Inst.*, 1912, p. 101; *Proc. Roy. Inst.*, 1917, p. 41; Howard Lectures (*Roy. Soc. of Arts*), 1914; *Berichte*, 46 (1913), p. 5; *Jour. Roy. Soc. Arts*, 1923; "Coal and its Scientific Uses," Longmans, Green & Co., 1918.

it may be said without exaggeration that whenever it can be conveniently applied "incandescent surface combustion" is the most perfect and economical way of burning gases and vapour yet devised.

ZUSAMMENFASSUNG

Das Thema dieses Berichtes umfasst ein so weites Gebiet, dass es nur möglich war, kurz auf solche Fragen einzugehen, die von allgemeinem Interesse zu sein scheinen. Der Stoff wird in 4 Abschnitten behandelt, nämlich (1) Thermische Betrachtungen, (2) Der Mechanismus der Verbrennung, (3) Explosive Verbrennung, (4) Katalytische und Glühoberflächen-Verbrennung. In jedem Abschnitt wurde versucht, den heutigen Stand der Wissenschaft und die von der Forschung befolgte Richtung anzugeben.

Thermische Betrachtungen. Es werden beschrieben (*a*) die thermo-chemischen Prinzipien in Beziehung zu den "Verbrennungswärmen," (*b*) die Funktion der "gasigen Äquilibrien" bei der Verbrennung und das Prinzip des beweglichen Äquilibriums, (*c*) die Wirkung der Dissoziation und der molekularen Wärmekapazität auf die "Verbrennungstemperatur," (*d*) Die Emission von Flammen-"Strahlungen."

Der Mechanismus der Verbrennung. (*a*) Die Verbrennung des Kohlenstoffs. Es wird auf frühere Anschauungen hingewiesen und ein Umriss des Werkes von Rhead und Wheeler und von Langmuir gegeben. Das umkehrbare Schema $2CO \rightleftharpoons C + CO_2$ und die Reaktion von Dampf mit glühendem Kohlenstoff werden betrachtet.

(*b*) Die Verbrennung des Kohlenoxyds. Es wird ein Umriss gegeben von den verschiedenen aufgestellten chemischen und physikalischen Erklärungen für H. B. Dixon's Entdeckung, dass ein trockenes $2CO + O_2$-Gemisch durch den gewöhnlichen elektrischen Funken nicht zur Explosion gebracht werden kann. Es wird auch kurz über die letzten Forschungen von W. A. Bone und F. R. Weston über (*a*) die Explosion von streng trockenen $2CO + O_2$-Gemischen und (*b*) Flammenspektren von Wasserstoff, Kohlenoxyd und Wassergas berichtet.

(*c*) Die Verbrennung von Kohlenwasserstoffen. Während des grössten Teiles der vorigen Jahrhunderts herrschte unter Chemikern geradezu das Dogma, dass der Wasserstoff in einem Kohlenwasserstoff vorzugsweise dann verbrennt, wenn Mangel an Sauerstoff besteht. Untersuchungen in Manchester (1891) und gleichzeitig auch in Leeds haben jedoch gezeigt, dass diese Ansicht falsch ist, und eine erschöpfende Reihe von Forschungen, die von W. A. Bone und Mitarbeitern in den Jahren 1900/06 ausgeführt wurden, bewiesen über allem Zweifel, dass das erste Stadium der Oxydation eines Kohlenwasserstoffes die vorübergehende Bildung eines unbeständigen "hydroxylierten" oder "oxygenierten" Moleküls bedingt. Die neuerdings aufgestellte Theorie der "Peroxydation" wird ebenfalls erwähnt.

Explosive Verbrennung. Die wichtigsten Forschungen und die bedeutendsten experimentellen Ergebnisse in jedem der folgenden Unterabschnitte dieses Abschnittes werden kurz besprochen: (*a*) Entzündungstemperatur, (*b*) Entzündung durch elektrische Entladung, (*c*) Grenzen der Entzündbarkeit, (*d*) Ausbreitung der Flamme und des Knalles, (*e*) Explosionen in geschlossenen Gefässen, (*f*) Explosionen von Gasen bei hohem Druck, (*g*) Das Problem des Klopfens in Benzin Luft-Motoren.

Katalytische und Glühoberflächen-Verbrennung. **Die katalytische Verbrennung bildet einen Teil des allgemeinen Themas der Katalyse, welches wahrscheinlich eines der wichtigsten in der modernen Chemie ist. Es wird kurz auf laufende Anschauungen und Forschungen sowie auf die von W. A. Bone und C. D. Mc.Court entwickelten und technisch angewandten "Glühoberflächen-Verbrennung" hingewiesen.**

THE GAS INDUSTRY AS A SOURCE OF DOMESTIC AND INDUSTRIAL ENERGY

THE JOINT FUEL COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS, THE SOCIETY OF CHEMICAL INDUSTRY, THE COKE-OVEN MANAGERS' ASSOCIATION, AND THE INSTITUTE OF FUEL

F. W. GOODENOUGH, C.B.E.

Paper No. G9

CONTENTS

The old truism, "Money saved is money earned," may well be adapted for the purpose of this Fuel Conference (and especially for that of a paper on "Gas as a source of Energy") to read "Energy saved is energy created."

The particular and outstanding services which the gas industry renders to modern civilisation are :—(1) that of making available from every ton of coal treated a higher percentage of its potential heat value than is secured by any other method of dealing with it which eliminates the smoke and dirt attending its direct combustion; (2) that of reducing to a minimum the expenditure of human energy required for the conduct of operations necessitating the use of heat.

The Gas Industry is Thermally Efficient

When the potential heat of coal is converted into electrical energy through the medium of steam engine or turbine, its use in that way to produce heat or power requires the employment of a large amount of human energy on dirty and exhausting work. The proportion of the potential heat made available to the consumer only reaches 20 per cent. (say, 58 therms per ton) in a very few cases; the average is substantially below that figure.

When coal is carbonised at a modern gas works, 25 per cent. of

its potential heat value—say, 72 to 73 therms out of a total of 290 therms per ton of coal—is obtained in the form of gaseous fuel, while half the total heat value (say 145 therms) is returned to the fuel market in the shape of coke and breeze. If that coke be then used to raise steam in a modern electric generating station, energy representing 25 to 30 therms will be rendered available to the community. There is, further, to be taken into account the highly valuable chemical by-products that are obtained from the carbonisation of coal and the subsequent distillation of the resultant tar and the treatment of the ammoniacal and cyanogen liquor residuals, which, measured in terms of calorific value, represent about 15 therms per ton of coal. (If measured in terms of value to industries of many and varied kinds[1] or of food productivity, in times of peace, or in terms of *national defence* in times of war, these chemical by-products of the gas works will be found to have an economic value far in excess of their calorific value.)

It is therefore seen that an undertaking which carbonised coal and then converted the residual coke into electrical energy could sell, as gas, as chemical by-products, or as electricity, from 112 to 118 (say 115) therms per ton of coal; whereas, if the same coal went to an electric generating station to be burned under the boilers, the best output of energy to be hoped for would be one-half that figure.

Coal Conservation

From the point of view of *coal conservation* (the conservation of our great national source of energy) the gas industry as a source of energy, therefore, stands easily first, and should receive every possible consideration and encouragement from those whose

[1] The subject of "The Use of Town's Gas in Industry" was dealt with exhaustively by Sir Arthur Duckham, K.C.B., in a paper presented to the World Power Conference in 1924, and it is unnecessary to repeat here all the facts therein set out. It is sufficient to state that in the past four years the use of gas as a fuel in industrial processes has rapidly increased. In the district of the largest gas undertaking, that of The Gas Light and Coke Company, of London—a district mainly residential and commercial—the sale of gas for industrial purposes already represents 11 per cent. of the total, and is growing rapidly. In Sheffield it has reached 45 per cent.; in Coventry 40 per cent.; in Smethwick 39 per cent.; in Redditch 35 per cent.; and similarly in every industrial centre in the country it has reached substantial dimensions and is growing rapidly year by year. A smokeless Britain is to-day no idealist's idle dream, but the practical man's hope and expectation.

business it is to study the nation's economic interests from all standpoints, that is, from the Government of the day, whatever its political colour may be, and from the Government departments particularly and permanently concerned.

The same conclusion will be reached from another line of consideration.

In the year 1927 (the year ended March 31, 1928 is taken where municipal undertakings are concerned) about 19,000,000 tons of coal were, it is estimated, carbonised in the gas works of the British Isles; and 1,500,000,000 therms of gas were supplied to sôme 9,250,000 consumers. Of this quantity, the writer estimates that 1,000,000,000 therms were used as domestic and general fuel and 125,000,000 therms as industrial fuel.[2]

At the time of fuel rationing during the Great War, it was found that from 50 to 75 therms of gas, say about 60 therms on the average, would do the useful work for the domestic consumer previously done by a ton of coal; and that 50 therms was on the average sufficient to produce the same output for the manufacturer as a ton of coal used for industrial heating. (These figures were, and are, bound to be only approximate, as the actual equivalents necessarily varied and would vary with the processes requiring the use of heat and with the plant employed and the conditions of working.)

Taking 70 therms per ton of coal as the average result obtained at the gas works, it will be seen that to do the equivalent work in domestic and industrial heating for which 1,125,000,000 therms of gas were required in 1927, a consumption of raw coal of over 19,000,000 tons would have been required,

$$\frac{1000}{60} + \frac{125}{50} = 19,160,000$$

as against $\frac{1125}{70} = 16,000,000$ tons carbonised; and whereas, on the one hand, from the 19,000,000 tons so required to be burned raw no residuals, either in the form of solid fuel or of chemical products, would have been recovered; on the other hand, from the 16,000,000 tons carbonised, 8,000,000 tons of coke, as well as large quantities of chemical by-products, were obtained for sale. The net conservation of coal resulting from carbonisation in place of combustion was, therefore, over 11,000,000 tons for the year.

[2] Sir A. Duckham, *loc. cit.*

Other Advantages

There is yet a further conservation of energy resultant from carbonisation in lieu of combustion to be taken into account, though here, as in the enormous conservation of human energy in home and factory, it is impossible to assess and state the conservation in pounds, shillings, and pence, or in horse-power-hours (or *woman-power*-hours). The further conservation referred to is that of property; of time; of human life; of health; and of the energy derived, both physiologically and psychologically, from cheerful as contrasted with gloomy surroundings—from "a place in the sun" instead of a place in the gloom, made possible by the progressive diminution of the smoke pall over our towns and cities, and the consequent increase in the hours of light and sunshine.

The following statements by Dr. R. Veitch Clark, M.A., M.B., the Medical Officer of Health for the City of Manchester (in a paper on "The Conservation of Human Energy," read at the annual conference of the British Commercial Gas Association at Plymouth in 1925), are typical of many that could be quoted to substantiate the claim just stated. Further evidence in abundance is contained in the Reports made to the Minister of Health by Lord Newton's Committee on Smoke and Noxious Vapours, published in 1921, and obtainable from H.M. Stationery Office.

> "There is nothing more profoundly ingrained into the psychology of our being than the beauty of light and the hateful ugliness of gloom. Everyone feels the stimulating effect of a fresh and sunny summer morning, and it is few, indeed, who do not react in the other way to the depression of atmospheric dinginess. This psychology of light is an enormously potent factor, and its actual material results have been demonstrated by the Industrial Fatigue Research Board in that the output of work was found to be notably diminished when lighting conditions were bad . . .
>
> The second aspect of the effect of sunlight on health which I wish to bring to your notice is what may best be described as the biological basis . . . . In the vegetable world, generally speaking, the whole of plant life depends upon the action of the sun upon the green colouring matter, chlorophyll. Plants grown in the dark or without sunlight are pale and sickly and weak in development. . . . The vitamins, which are of such essential value in fresh food as preventatives of scurvy, rickets, incomplete development of the bodily framework, and many other conditions, are all the direct or indirect result of the stimulating action of the sun upon vegetation. All the food values of vegetables, root crops, fruits, or ordinary green vegetable food are therefore directly dependent upon the

sun's rays. In man we have abundant proof equally from many extensive scientific investigations of his need of sunlight. . . . . I would refer particularly to the work which was done in Vienna by Dr. Harriet Chick. . . . . Our knowledge of the physical condition of children in industrial centres and the prevalence of rickets amongst them is very largely explained by these researches. It would be difficult to exaggerate the importance of the facts which are thus revealed.

One more striking piece of work carried out at Columbia University in the United States of America revealed the remarkable fact that the chemical constitution of the blood in the human being varies according to the seasons, inasmuch as the phosphorus and calcium (or lime) in the blood are at their lowest in March and highest at the end of summer and autumn. . . . .

The artificial sunlight treatment obtained by the many forms of lamps now on the market supplies the ultra-violet rays, and the successes of this treatment are altogether beyond question. There is, however, no doubt but that the natural sunlight supplies the stimulation to the whole bodily activity, and the open air, the cooling breezes of hill or seashore, contribute to a very great degree towards the permanent raising of the health level and the establishment of physical vigour on a firm basis.

One might amplify in other directions the profound influence which sunlight has upon the bodily welfare of the individual, but enough has been said to demonstrate the properties possessed by solar radiations, and the importance of adopting any procedure which will enable those radiations to reach our bodies in the natural way in ordinary life. . . . . Finally, and this is for the moment by far the most important, the passage of ultra-violet rays is very greatly interfered with by even a slight smoke haze. Not even so much as the greyish sky which is supposed to be the natural condition in our industrial areas, but a much less pronounced haze through which the ordinary sunlight can, to a considerable extent, penetrate is quite enough to filter off a very large proportion of the ultra-violet radiations. How much more, then, does the ordinary smoke cloud deprive us of this source of health and well-being. . . . .

Another chart shows the comparative light received throughout each of the twelve months of the year by Manchester, Southport, Brighton, and Eastbourne. Even allowing for the fact that the climatic conditions vary naturally, it is a disgrace to our modern civilisation that in the height of summer the Manchester sun records should only slightly exceed the winter one of these other places.

. . . . If our water were as dirty as our air we would either have a revolution or we would cease to exist. Many years ago, Dr. James Niven, formerly Medical Officer of Health for Manchester, was asked for his views as to the principal cause of the high death rate in industrial areas, and with his typical laconic directness, he replied, "The answer is 'dirt'!" And to this day the answer is the same.

> It is recorded by Sir George Newman in his last annual report to the Ministry of Health that one of the most distinguished foreign Medical Officers of Health recently visiting this country, when asked what impressed him most in England, replied that it was the neglect of vaccination in the country of Jenner, the bad crowded housing conditions and the smoke pollution of the atmosphere. It is our duty as a nation to get rid of this reproach. It is a crying evil due to a neglect both unbusinesslike and inhuman."

No statistics are available or evidence on record as to the saving of human energy effected by the substitution of gas for the use of nearly 17,000,000 tons of coal in the homes of the people of this country, or of 2,500,000 tons in our workshops and factories; but it is probably a conservative estimate to say that, on the average, one-third of the work of one domestic servant is saved per household in which gas is employed as fuel—in many cases the number of servants has been reduced by one, in some by as much as two. On this basis, it may be calculated that the work of 3,000,000 domestic servants is regularly saved by the use of gas instead of raw coal. The writer regards this as an under-statement of the facts. For the saving of stokers' time in workshops and factories due to the use of gaseous fuels no basis of calculation is available; but the handling of 2,500,000 tons of coal per annum (say 1,000 tons per working hour) and the resultant ash, and the tending of the fires in which that quantity would be burned if gas were not used, would obviously entail the employment of a large number of men, rendered unnecessary by the use of gas.

Viewed from every standpoint, the gas industry, by its constant development of efficient appliances for providing fuel for every kind of domestic and industrial process requiring heat—including, at its latest development, the use of heat to promote refrigeration —is both a great agent for the conservation of energy and a highly efficient source of energy, alike in the home and in the factory; and all the evidence proves that it is being recognised and utilised as such in growing measure every year. That evidence may be crystallised in the figures published by the Board of Trade for the make of gas by statutory undertakings in England, Wales, and Scotland, in the past quarter of a century:—

Year		*Million cu. ft.*
1903	...	159,864
1913	...	219,105
1923	...	259,850
1927	...	297,697

Future Progress

The remarkable development which these figures indicate has taken place despite the antiquated legislation which governs the gas industry in Great Britain. Seeing that England was the birthplace of public gas supply, it is perhaps not surprising that much of the legislation controlling it dates back eighty years, but if the householder and industry generally are to secure in full measure the benefits resulting from the widespread use of gas, it is essential that the industry should be freed from the cumbersome and useless shackles which restrict its full development, and that the control of this great public service should be based on modern needs and modern conditions. For instance, gas undertakings should be enabled, as they are in other countries and as are other public utilities in England, to offer such scales of charge as will enable both domestic and industrial users to avail themselves to the utmost of the advantages which a gas supply provides. Furthermore, every facility should be given gas undertakings to co-operate one with another, and with allied and ancillary industries, for the more economic production and supply of gas. In the matter of gas legislation, England lags behind probably every other nation.

RÉSUMÉ

L'auteur démontre l'importance de l'industrie du gaz dans la vie nationale et il parle des services remarquables que cette industrie rend à la civilisation moderne. Au point de vue de la conservation du charbon, l'industrie du gaz en sa qualité de source d'énergie devrait recevoir tout encouragement possible de la part de ceux qui ont à s'occuper de l'étude des besoins économiques de la nation. De remarquables progrès ont eu lieu au sein de l'industrie du gaz au cours de ces dernières années malgré la législation surannée qui la gouverne. Il est tout de même essentiel que cette industrie s'affranchisse des entraves inutiles et embarrassantes qui restreignent son développement complet; il faut que le contrôle de ce grand service d'utilité publique se fonde sur les besoins et les conditions modernes Pour la législation sur le gaz, l'Angleterre est probablement le pays le plus retardataire de tous.

THE UTILISATION OF COKE OVEN GAS BY THE GAS INDUSTRY

THE JOINT FUEL COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS, THE SOCIETY OF CHEMICAL INDUSTRY, THE COKE OVEN MANAGERS' ASSOCIATION AND THE INSTITUTE OF FUEL

T. P. RIDLEY

Paper No. G10

CONTENTS

GENERAL EXAMINATION OF THE PROBLEM

The gas industry, which in magnitude is second only to the railways among public utility undertakings, has a most enviable record for trustworthiness as a public service over a period of nearly 120 years, and to-day is more vigorous, successful and better managed than at any other period of its long history. As evidence of successful growth and management it may be stated that, notwithstanding all the governmental restrictions to which it is subject and the difficulties experienced as a result of labour troubles in other industries, it has grown since pre-war days to the extent shown by the following figures, which only represent the statutory undertakings:—

	1913.	1925.
Quantity of gas sold ...	201,595 million cu. ft.	265,757 million cu. ft.
Increase		31·8 per cent.
Number of consumers ...	6,917,747	8,200,455
Increase		18·5 per cent.

and each year shows a further expansion of these figures.

Progress has been made also in manufacturing results. "Field's Analysis" for 1913 shows for 33 undertakings an average make of gas per ton (2.240 lb.) of coal carbonised of 11,799 cu. ft.; in 1927 the average was 14,108, an increase of 2,309 cu. ft. per ton and this with an increase in saleable coke of 0·4 cwt. and 0·4 gallons

of tar per ton of coal carbonised. These figures show solid and substantial progress.

On the other hand it is admitted that, with a few admirable exceptions, the by-product coking industry has made very little progress since 1913. The number of modern ovens erected since the armistice is very small, whereas in Germany plants are being reconstructed with ovens of the latest and most economical type at a remarkably rapid rate. The labour costs in this country per ton of coke produced are very high, the coke produced per man per day being considerably less than that of modern practice. Our plants in the majority of cases are so inefficient and expensive by comparison with those of other countries that eventually they must be rebuilt or abandoned, otherwise they will not be able to compete in the world's markets, and iron and steel makers in this country will not be able to pay the prices which uneconomic costs involve, with the result that they may be compelled to import coke. The coke oven owners say they cannot undertake the cost of reconstruction unless they can sell the greater quantity of surplus gas which will be available after reconstruction.

The majority of coke ovens in Great Britain are associated with collieries, which in the past have found it more profitable to make and sell coke and other products than to sell certain classes of coal *as coal* and coking plants have been erected generally in small units of 200 to 300 tons per day to deal with small coal or slack produced at a particular pit, whereas in Germany they are in most cases in close proximity to large steel works where large quantities of the coke oven gas can be and are being utilised. Like several other industries the coke oven industry has felt the depression in the iron and steel trade, the bad effects of the mining dispute, the decline in exports and the fall in values of coke, tar and sulphate of ammonia. Consequently they find it difficult to operate on a basis which provides sufficient, if any, profit. They are therefore making—and quite rightly—strenuous efforts to improve the position of their industry. They consider that one way in which this can be done is to sell to the very best advantage any surplus gas which they now have or which by reconstruction of plant they may have available. At present there is very little surplus gas that is not utilised in some way, but probably it is not all utilised in the most profitable manner. If, however, the coke oven owners can—as it seems certain they must—reconstruct their present plants or put down new and additional plants, there will be considerably more surplus gas to be utilised than there is at present. Additional

plants, however, will be limited by the amount of coke which can be sold. The coke oven owners have come to the conclusion that the gas industry can afford to pay the best price for their surplus gas and have therefore started a campaign for the extension of the use of coke oven gas for town's purposes. It is understood that they are not recommending the universal use of coke oven gas by gas undertakings throughout the country, but only where the circumstances of geographical position justify its serious consideration. They have, however, gone to the length of suggesting that in certain circumstances gas undertakings should be compelled to purchase any available surplus coke oven gas at such prices as may be fixed by a third party in default of agreement between the gas undertakings and themselves.

In Great Britain the gas industry is considerably larger and the coke oven industry considerably smaller than in Germany, and the prices charged to the public for gas are lower generally in Great Britain than in Germany. The gas industry very naturally vehemently objects to any compulsion in the matter of taking outside supplies.

In Germany the efforts of the coke oven industry are not confined to disposing of their surplus gas to gas undertakings near to or far from the ovens—such is only one of the items in large schemes for utilisation of by-products. The use of surplus gas is contemplated in the synthetic production of ammonia, nitric acid, oils and methanol and the hydrogenation of coal. The development of scientific and economical treatment of other by-products is also to be taken in hand. Germany has also another object in view in its long distance gas scheme, and that is to cut out the import of British coal.

It is the object as it is the interest of the gas industry to sell gas to the public at the lowest possible economic price. This is also in the national interest. Therefore, if coke oven gas can be supplied to the gas undertakings on terms and conditions which will enable gas to be sold to the public at lower prices than would otherwise be the case, there is no reason why the utilisation of such gas by the gas industry should not extend; on the contrary, it should be welcomed. Prejudice cannot be allowed to stand in the way. On the other hand it cannot be expected that the gas industry will purchase gas from outside itself unless the result is going to strengthen the gas industry still further in developing the sound position already attained by foresight and enterprise.

The rate of progress in the use of coke oven gas by gas undertakings has been retarded in Great Britain by reason of the fact that the

coke oven owners have not sufficiently realised the difficulties of gas undertakings with regard to the statutory obligations under which they work, and which they feel they must faithfully carry out at all costs. A further cause has been that the coke oven owners in many cases have asked prices for their gas which were economically impossible for gas undertakings to pay.

CONDITIONS OF CONTRACT FOR A SUPPLY OF COKE OVEN GAS

In giving consideration to the making of a contract for a supply of coke oven gas the important general conditions may be summarised under three headings as follows:—

1. The supply of gas must be reliable as to the constancy of an agreed calorific value, purity and pressure.
2. There must be freedom from failure of supply and, if there be any doubt regarding this, means must be provided by the gas undertaking to make up any deficiency of supply from the coke ovens in order at all costs to avoid failure in the gas undertakings' statutory obligations to the public.
3. The price must be such as, with the addition of all direct and indirect costs involved as a consequence of purchasing supplies of coke oven gas, will be less than the estimated cost of making gas at the gas works during the period of the contract, taking into consideration the gradually increasing efficiency of gas works plant.

Statutory Obligations of Gas Authorities. With regard to *general condition No.* 1, which relates more particularly to quality, the statutory conditions (summarised) are:—

(1) The gas supplied shall at all hours:—

(*a*) be of such calorific value as the undertaking shall have declared and which cannot be altered except by three months' notice to the Board of Trade and to every consumer,

(*b*) not contain any trace of sulphuretted hydrogen when tested in accordance with certain conditions,

(*c*) be supplied at a minimum pressure of not less than 2 in. in any main or in any pipe laid between the main and the meter having an internal diameter of 2 in. and upwards.

Gas referees are appointed by the Board of Trade and the gas supplied by a gas undertaking is tested under very strict regulations prescribed by such referees. The tests are made by Gas Examiners appointed by Local Authorities. If no such examiners are appointed or if the testing is imperfectly attended to, Quarter Sessions on the application of at least five consumers may appoint an examiner. A Chief Gas Examiner is appointed by the Board of Trade.

Penalties for failure (if the circumstances are within the control of the Gas Undertaking):—

(a) £5 for every complete 1 per cent. in excess of 5 per cent. below the declared calorific value for two hours or upwards per day,

(b) not exceeding £10 for each occasion on which the gas does not conform to the provisions as to purity or pressure.

It is further provided that if in any quarter the average calorific value of the gas as shown by the tests referred to, is less than the declared calorific value, a sum, which the Chief Gas Examiner shall determine to be as nearly as may be the amount by which the revenue of the gas undertaking has been improperly increased, shall, in the case of a Local Authority Ownership be applied towards a reduction in the price of gas and in any other case is deducted from the amount applicable to payment of dividend on the *Ordinary* capital of the undertaking.

It is usual, however, and considered by most gas undertakings to be essential, though not prescribed by statute, that the gas sent out shall not contain more than 1 grain of naphthalene and 1 grain of ammonia per 100 cu. ft. and generally shall be free from other injurious impurities.

In a contract for the supply of coke oven gas not only must there be a prescribed minimum number of B.Th.U. per ft., but also a maximum, for the reason that if the declared calorific value of the undertaking be 500 B.Th.U. per cu. ft. and the gas supplied be of 550 B.Th.U. the consumer will use less volume and the undertakers will only be paid at the rate of 500 B.Th.U. or practically 10 per cent. less than the value actually supplied. In addition, great variations cause inconvenience to consumers in the use of their appliances.

Mr. W. J. A. Butterfield, in his inaugural address to the London Section of the Society of Chemical Industry on October 3, 1927[1] shows how little variation in calorific value there is in actual practice in the gas supplied by gas undertakings. Gas undertakings in purchasing coke oven gas limit their freedom in the calorific value which they may declare, as there is greater flexibility in this respect when manufacture is carried on at the gas works. It may be accepted, however, that gas of a composition satisfactory to gas undertakings can be sent out from coke ovens—such is being done at Middlesbrough, Sheffield and other places at the present time.

With regard to *general condition No.* 2, dealing with continuity of supply, the statutory obligation is to give and continue to give a supply of gas at every hour of the day and night to every owner or occupier of premises within 25 yards of a gas main who may require

[1]*Gas Journal*, February 14th, 1928, Carbonisation Conference Supplement.

such a supply and to every public gas lamp within 50 yards of a main which may be required by the Local Authority to be supplied.

In the mining disputes of 1921 and 1926 the supplies of gas from coke ovens were either entirely discontinued or greatly reduced in practically all cases as is shown by the figures on Appendix "A."

The possibility of failure of coke oven supplies undoubtedly does exist, and therefore it is imperative that gas undertakings should maintain stand-by plant of capacity at least sufficient to take over the whole coke oven supply and this plant must be of such a character that it can be put into operation quickly. It may be considered to be a waste of capital but the possibilities of labour troubles at the coke ovens, owing to their close proximity to the pits, cannot be overlooked. In some cases it is necessary to erect new plant and also to keep workmen un-economically employed, so that they may form a nucleus gang for starting-up gas making plant at the gasworks in cases of emergency. It is also necessary to maintain stocks of coal at the coke ovens or the gasworks, or both. It would appear desirable to keep large stocks of coal at the gasworks rather than at the coke ovens, because it can be conceived that circumstances connected with mines and railways may arise under which stocks of coal at the coke ovens could not be utilised. Where the coal stock is only at the gasworks it is desirable to provide, in the contract, that the coke ovens will lay down stocks of coal if requested so that in the event of labour troubles at mines or on the railways becoming imminent, stocks may be laid down at the ovens. This request will be made only if it is thought probable that the coke oven men will continue at work. The contract should also provide that the coke oven owners will, if required, purchase foreign coal in the event of being unable to obtain home supplies.

In Germany the question of failure to maintain supplies of gas is not considered in so serious a light as in this country. No special Acts of the Legislature exist regulating the supply of gas. The gas undertakings can make themselves exempt from liability for non-delivery or limited delivery of gas. The terms of contract of one large city are:—

> "The supply can at times be discontinued if and as far as it is necessary owing to disturbances in the establishment, to strikes in the undertakings, or for other reasons."

There has not been the number of failures of supply in Germany as here (in Essen there has only been one failure in 18 years), and there is less likelihood of failure because the coke oven interests are associated and the various coking plants pump gas, purified at the

ovens, into interconnected mains and consequently gas undertakings are not dependent upon any one plant. So satisfied are they that in some cases they are content to discontinue entirely the gasworks and utilise the site for other purposes.

If the coke oven owners of this country or of the respective coking coal fields associated their interests and supplied their gas into a system of grid mains so that gas undertakings were receiving from a group of plants instead of from one plant, the risk of failure would be reduced; but this would not eliminate the labour risks to which coke ovens are subject, which risks are much greater than at gasworks and greater also than at German coke ovens.

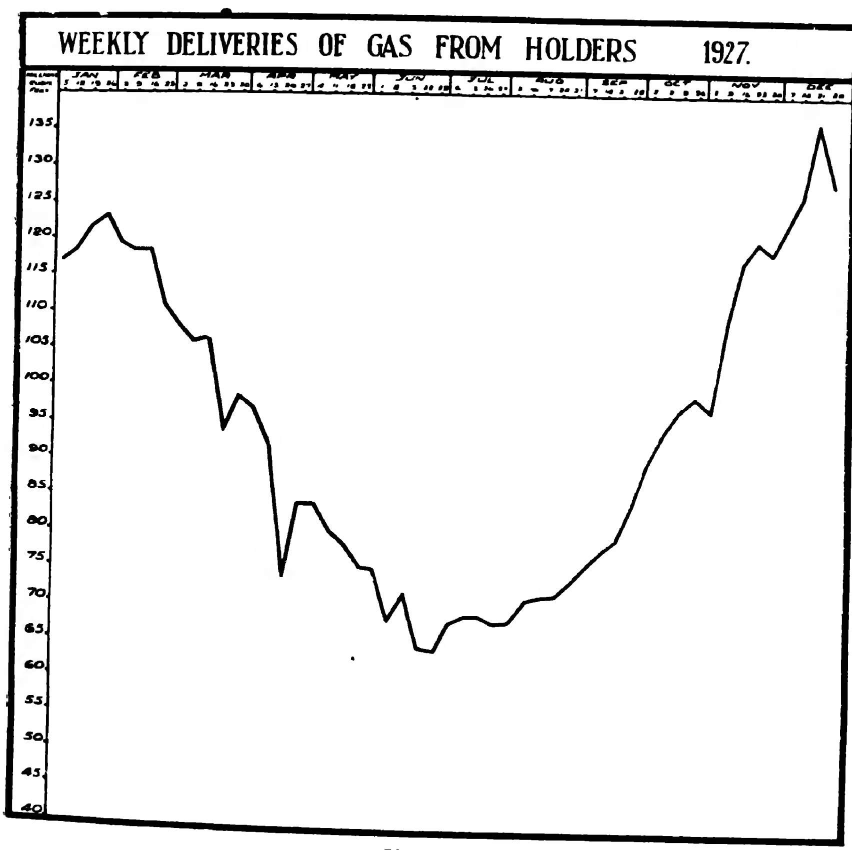


Fig. 1.

So long therefore as present legislative penalties with regard to continuity of supplies to the public continue, so long must gas undertakings who take coke oven supplies continue to maintain conditions which will enable them to avoid failing the public in the

event of failure on the part of the coke ovens to supply the gas undertakings. This fact whilst not preventing an increased use of coke oven gas by gas undertakings must prevent the fullest development of its utilisation by reducing the economic price which gas undertakings can afford to pay for the gas, and must also create in the minds of some the thought that it is a risk too great to be undertaken.

Determination of Price.—With regard to the third condition which is that of price, many factors must be taken into consideration, and in the past some of these have not been given the full attention they deserve. The price must be dependent upon the whole of the circumstances in each individual case.

The first question to be settled is the relation which the quantity of gas to be purchased bears to the total quantity delivered by the gas undertaking, that is, is the contract to be for (*a*) the whole requirements; (*b*) an equal daily quantity or approximately so throughout the year, leaving the gas undertaking to manufacture the costly peak load demands; (*c*) the peak load demands, leaving the gas undertaking to manufacture the equal daily quantity. The economic price payable will of course differ considerably as between the three classes of contract.

The load of a gas undertaking is very variable as between summer and winter. This is shown by Fig. 1 which gives the weekly demands in 1927 in an industrial area.

The total delivery for the year of the undertaking in question was 4,900,000,000 cu. ft. or an average of 94,000,000 per week, but the demand varied from 64,000,000 to 137,000,000 per week.

TABLE I

VARIATIONS IN DAILY GAS OUTPUTS AT DIFFERENT PERIODS OF THE YEAR.
Figures in *millions* of cubic feet.

January.		April		June		July/August		October		December.	
						July					
1 Sat.	14·9	11 Mon	14·1	1 Wed	11·3	29 Fri.	10·5	3 Mon.	13 5	20 Tues	20
2 Sun	13 8	12 Tues.	13 9	2 Thurs	10 8	30 Sat	9 5	4 Tues	14 1	21 Wed.	20
3 Mon.	15 3	13 Wed	12·9	3 Fri	10 6	31 Sun	9 2	5 Wed	13·6	22 Thur.	19
4 Tues.	18·6	14 Thurs	12·5	4 Sat	9·2	August.		6 Thurs	13 3	23 Fri	20
5 Wed.	18·0	15 Fri.	10 0	5 Sun	9 1	1 Mon.	7·4	7 Fri	13·5	24 Sat.	18
6 Thurs.	17·4	16 Sat	10 2	6 Mon.	7 6	2 Tues.	10 8	8 Sat	12 4	25 Sun	17
7 Fri.	18 2	17 Sun.	9 8	7 Tues	10·2	3 Wed	10·8	9 Sun.	12·0	26 Mon.	15
8 Sat.	16·5	18 Mon.	8 4	8 Wed	10 8	4 Thurs.	10·6	10 Mon	13·7	27 Tues.	1[illegible]
9 Sun	14 7	19 Tues	11 2	9 Thurs	10 8	5 Fri.	10 5	11 Tues	14·7	28 Wed.	1[illegible]
10 Mon.	17·2	20 Wed.	11·7	10 Fri	10·5	6 Sat.	9·5	12 Wed.	14·5	29 Thur.	1[illegible]
						7 Sun.	9 2				
Highest	18 6		14 1		11 3		10 8		14·7		2[illegible]
Lowest	13·8		8 4		7·6		7·4		12 0		15
Difference between Highest and Lowest	4·8		5·7		3·7		3·4		2·7		[illegible]

Not only are the weekly loads very variable, but the demands from day to day differ considerably as is shown for sets of ten consecutive days in various months of the year (Table 1).

The lowest daily demand was 7·4 million cu. ft. in summer and the highest 20·8 in winter. The figures show variations of 4,000,000 to 5,000,000 cu. ft. within a few days, and this is in a district where fogs are very infrequent.

Where coke ovens are supplying the total requirements of a gas undertaking, it is clear that in the summer they must utilise gas for other purposes or waste it. In Germany the conversion of ovens to the *compound* type enables them to heat the ovens by producer gas made by low grade coal or coke, by blast furnace gas, or by good coke oven gas, as circumstances may dictate. These plants therefore provide greater flexibility with regard to sales of gas and coke. In this class of contract the gas undertaking can afford to pay a higher price than if it continues to provide peak loads.

With regard to the case where the coke ovens supply a level load and the gas undertaking manufactures the peaks, the total quantity of gas which the gas undertaking can purchase is only about 50 per cent. to 60 per cent. of its total annual deliveries. It is obvious that the cost of making the balance must be very much higher than that of the level load or the average of the total deliveries. Consequently the gas undertaking cannot afford to pay for coke oven gas anything like its present average cost of making gas and delivering it into holders. Most of the coke oven gas sold in Great Britain is under this class of contract, whereas in Germany the total requirement contract is the greater sale.

In the case of the gasworks manufacturing a level load, and the coke ovens supplying the peaks, the position is reversed and the gas undertaking will of course be in a position to pay a higher price. This class of contract has been introduced in Germany, but I am not aware of any such contract existing or contemplated in Great Britain at present.

Sliding Scale.—All contracts should provide for increases and decreases in price in relation to general cost of manufacture, and for this purpose a sliding scale based on the price of coal is probably the most satisfactory to both parties. For this purpose it is necessary to fix a standard price of coal.

Charges to be borne by Gas undertaking.—A gas undertaking considering the question of a contract for a supply of coke oven gas and having settled the type of contract and the quantity of gas to be purchased, will find it desirable to make up two statements of total

money costs. The greater the detail in which these two statements are made up the greater will be the accuracy attained in ascertaining the costs which continue, or partially continue, and those which entirely cease if coke oven gas be purchased.

Statement "A" should show the cost of gas into holder if gas be continued to be manufactured at the gas works with coal *at the standard price*, and statement "B" should show the cost of gas still to be manufactured at the gas works with coal at standard price and take into account how each item of cost will be affected by the reduction in quantity manufactured and be adjusted for the following items or such of them as may be involved:—

Purification if gas not supplied purified The gas works having purifying plant, capital expenditure is saved if such plant is utilised.

Alterations at works for sectionalising plant necessitated by the purchase of outside gas.

Repairs to existing plant put out of action so that such may be in a condition to be utilised as stand-by plant.

Maintaining stand-by plant in condition of readiness.

Allowances to employees displaced if such allowances are not to be paid out of existing Pension Scheme funds

Nucleus gang for starting up stand-by plant if not economically employed meantime.

Extra stock of coal, coke and oil for carburetted water gas plant, plus additional handling, if any.

Standing charges which are increased per ton of tar distilled if the undertaking distils its tar.

Carburetted water gas. It may be necessary to use a larger quantity of oil owing to the calorific value of the coke-oven gas being lower than the coal gas displaced at the gasworks

New plant required to be provided as stand-by plant, or for any other reason due to the purchase of outside gas, *i e*, increased gasholder capacity, measuring or purifying plant

Sinking Fund to provide at expiration of contract a sufficient sum to construct or reconstruct plant necessary to take up manufacture of gas represented by the contract quantity

Reconstruction of plant which may be saved if such is not wholly provided for in repairs and maintenance of works in Statement "A."

State Insurance, Workmen's Compensation, Profit Sharing and Superannuation contributions which may be saved.

Margin required by gas undertaking to cover improved future efficiency of gasworks manufacture, including the results of the possible introduction at gasworks of Synthetic processes and from which they will be debarred; also to cover loss of freedom with regard to the most economical declarations of calorific value of gas which they may supply, and for other risks.

The balance between the statements "A" and "B" will be the sum which divided into the quantity of gas to be taken will be the price

per 1,000 cu. ft., or per therm, which the gas undertaking can afford to pay for the gas proposed to be purchased. The price thus ascertained is on the assumption that the gas is delivered through mains laid and maintained (including way-leave rents), at the cost of the coke oven gas suppliers and that the gas is paid for on measurement at the gasworks. Otherwise interest and redemption of the cost of the mains over the period of the contract, way-leaves, maintenance, and loss in transit of gas must be taken into account and consequently a reduced price be payable by the buyer. It appears desirable that the sellers should supply the commodity delivered at the gas works as there is a risk that the sellers may be unable to continue in business in which case the gas undertaking would be saddled with a loss of capital. There is no risk of the gas undertaking being unable to continue in business. In the new long distance scheme in Germany the gas undertakings are not called upon to provide capital for mains.

From the foregoing it is quite obvious that a flat economic price payable by all gas undertakings, even in the same neighbourhood, is impossible; and therefore every sale must be decided on the circumstances of the individual case. The economic price in respect of a certain quantity of gas for an undertaking may differ from that for a further quantity for the same undertaking, inasmuch as the first quantity may displace gas manufactured under expensive conditions whereas the further supply may displace gas manufactured much more cheaply. Each case presents different factors demanding careful commercial and technical judgment.

Coke oven owners must of course take into account all costs direct and indirect which they will be called upon to incur, and weigh up whether it will pay them better to supply gas to the gas industry, or utilise the gas in other ways.

With regard to transmission costs, Mr. Stephen Lacy in his paper read before the Institution of Gas Engineers in June, 1928, gave some interesting figures; as did also Dr. E. W. Smith in his paper read before the Midland Section of the Coke Oven Managers' Association in January, 1927.

EXTENT TO WHICH COKE OVEN GAS CAN BE ABSORBED BY THE GAS INDUSTRY

The numbers of gas undertakings in 1926 were 784 statutory and 597 non-statutory. As the latter represent a sale of only 7,500,000,000 cu. ft. out of a total of 284,000,000,000 cu. ft., and are generally in isolated places, they may be ignored from the

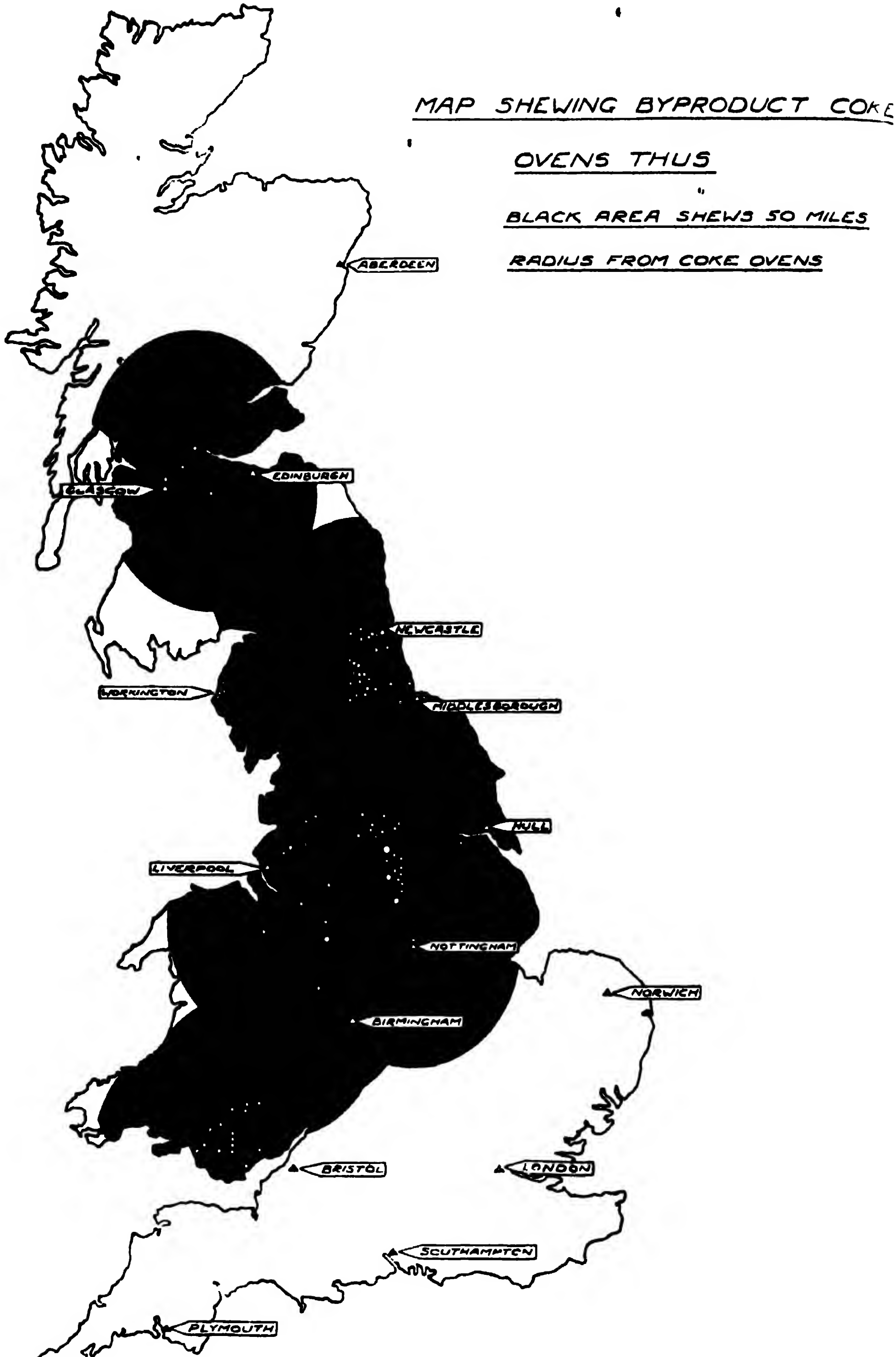

MAP SHEWING BYPRODUCT COKE
OVENS THUS
BLACK AREA SHEWS 50 MILES
RADIUS FROM COKE OVENS
ABERDEEN
EDINBURGH
GLASGOW
NEWCASTLE
WORKINGTON
MIDDLESBOROUGH
HULL
LIVERPOOL
NOTTINGHAM
NORWICH
BIRMINGHAM
BRISTOL
LONDON
SOUTHAMPTON
PLYMOUTH

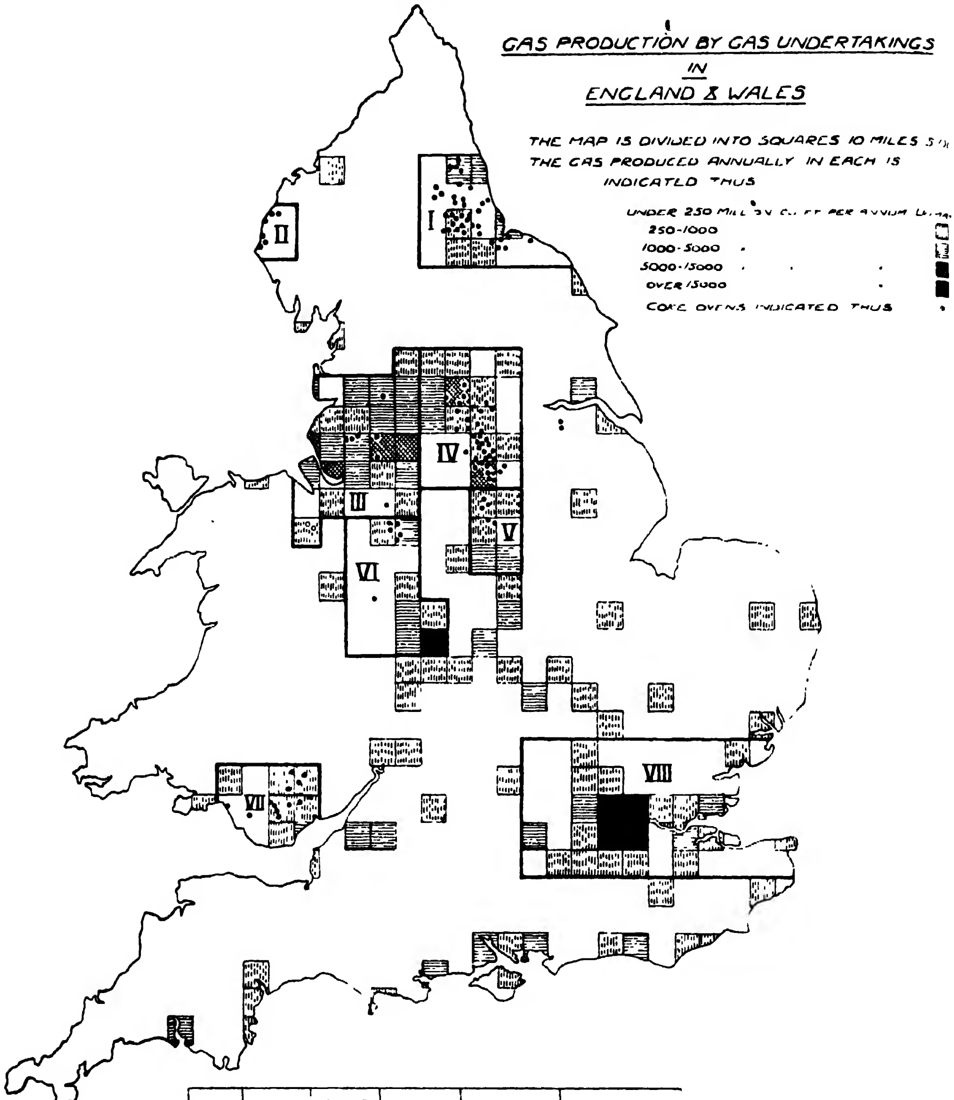
Fig. 2.

point of view of providing the possibility of any material extension of the utilisation of coke oven gas.

Appendix "B" is an analysis of the quantities of gas sold by the various statutory gas undertakings in each county, showing a total of 276,568,000,000 cu. ft. From this it will be seen that the undertakings selling less than 250,000,000 cu. ft. per annum number 630, and a further sixty-five undertakings sell less than 500,000,000 cu. ft., the two classes representing a total sale of 63,930,000,000 cu. ft. The individual sales of these undertakings are so small that taking geographical position into account many will not be attractive to coke ovens, unless they are on the route to some other large supplies.

Fig. 2 is a map showing the location of coke ovens in Great Britain and the area within 50 miles radius of any coke ovens. It shows that South Scotland, North and Middle England and all of Wales are covered, and that the Eastern Counties, London and most of the Southern Counties are outside of the radius. The principal places of gas consumption uncovered have cheap water transport and markets for coke at good prices, whereas coke oven gas would be hampered by long transmission costs.

There are not any published records of the quantities of coke oven gas available for purposes other than the heating of ovens. An attempt has been made to give an estimate (see Appendix "C") of the quantity of gas available based on 1,000 cu. ft. from waste heat and 6,000 cu. ft. from regenerative ovens per ton of coal carbonised, and on the coal carbonised in by-product ovens in 1925 in the districts given in the annual report of the Secretary for Mines This will provide an indication of the possible quantities of coke oven gas which might be available in the various districts. Against these figures is shown a year's sale of gas by gas undertakings and the quantities of coke oven gas purchased by gas undertakings in the various districts. From this an idea can be formed of whether the whole of the gas at present produced and not used for oven heating could be utilised by the gas industry within the 50 miles radius, but it must not be forgotten that the figures of available coke oven gas shown in Appendix "C" are on the assumption that surplus gas is not utilised for any other purpose than the supply to gas undertakings. This, of course, is not the case in practice. As stated previously, there is very little gas wasted but all that is now used may not be utilised as profitably as if it were sold to a gas undertaking. An approximation can also be arrived at of the quantity of surplus gas if the same quantity of coal be carbonised in the latest type of ovens.



AREA	No OF GAS UNDERTAKINGS	ANNUAL SALES OF GAS MILL CU FT	No OF COKE OVEN UNDERTAKINGS	PERCENTAGE OF BY PRODUCT OVENS	ANNUAL CONSUMPTION OF COAL BY OVENS MILLION TONS
I	38	12 026	37	80	3 6
II	8	350	6	100	0 6
III	106	43 886	9	100	0 8
IV	92	22 746	38	82	5 9
V	19	6 696	5		
VI	45	22 677	7	100	0 8
VII	35	5 163	13	65	1 9
VIII	95	101 737	–	–	–

Prepared by T. Hardie, [illegible] M.Inst C E., and published with his permission.

Fig. 3.

If all the coal at present carbonised in waste-heat and at regenerative coke ovens was carbonised in compound ovens there would not be nearly sufficient surplus gas produced to meet the total town gas sales of Great Britain. To extend the carbonisation of coal at coke ovens to produce sufficient gas to meet such sales would produce more coke than is at present sold by coke ovens and gas works combined -and there is already a world over-production of coke.

Fig. 3 again shows the location of coke ovens and also shows the production of gas by gas undertakings of various sizes in each of eight districts.

Direct Supply of Coke Oven Gas for Industrial Use

With regard to the suggestion which has been made in some quarters that coke ovens should supply gas direct to large industrial users, it must be remembered that for many years, and particularly in recent years, gas undertakings have been cultivating the industrial use of gas and special departments have been set up in the large undertakings to deal with such. In Birmingham the proportion of gas sold for industrial purposes has been increased from 5 per cent. of the total sales in 1911 to 30 per cent. in 1927. In Sheffield the sales of gas for industrial purposes represent 45 per cent. of the total sales. The gas industry has done a great deal of propaganda work and done much to improve gas apparatus for manufacturing purposes, in each district designing plant to suit the particular trades of the district. Much has been achieved notwithstanding the severe restrictions under which the gas undertakings have worked with regard to prices and dividends. The industry has asked the Government to give it greater freedom with regard to charges and if this be obtained the gas industry will be in a very much better position than hitherto to compete for industrial business having good loads and requiring large quantities. In Germany the coke oven owners are prepared to supply gas for industrial uses within gas undertakings' areas, through the gas undertakings themselves, and to sell such gas at lower prices if the gas undertakings pass on to the industrial consumer a large proportion of the price advantage.

With regard to the sale of unpurified gas, after taking into account the low cost of purification and the cost of special mains and storage which would be necessary, it does not appear to be worth while in this country to develop the sale of unpurified gas as against purified gas. Many town gas undertakings have had powers for years to

supply crude gas, but in no case has it been found worth while to exercise the power.

The solution of cheap gas for industrial purposes is not in the sale of unpurified gas, but in the sale of purified gas, using the distributing systems with which the gas undertakings are already equipped, and by the gas undertakings obtaining the power they are seeking to sell gas for industrial and other purposes on terms which bear a more correct relationship to the cost of giving such supplies than at present operates and under which the large consumer bears an undue proportion of fixed costs.

Sale of Coke

The question of supplies of coke oven gas to the gas industry is closely bound up with the question of the sale of coke. The primary object of the coke oven industry was originally the production at the lowest possible cost of hard coke suitable for the iron and steel industries. The coke oven owners are however now doing their utmost to secure the markets long held by the gasworks for softer coke, because these are markets in which higher prices are generally obtained. If gas undertakings should find difficulty in disposing of their coke of present type, they will so adjust their methods of manufacture as will enable them to produce whatever coke meets the public demand, even to the extent of erecting modern coke ovens in the gas works which can be worked to meet summer and winter demands in a much more flexible manner than the present regenerative ovens. If necessary, more amalgamations and association of interests of gas undertakings will take place. In these ways the gas undertakings would widen their market for coke by being in the position to supply both soft and hard coke. Gas undertakings are in the advantageous position that they are usually surrounded by a domestic market, with consequent low transport costs on coke, whereas in most cases the coke ovens are not so well placed in this respect. Such a development might result in restricting the quantities of coke oven gas, which the gas undertakings might purchase from outside.

Future Developments

The quantity of coke oven gas purchased by the gas industry from coke ovens has been gradually increasing during the last few years as is shown by Appendix "A." The year 1929 will show a greater increase than in any previous year owing to new contracts recently made coming into operation. The quantity which coke

ovens will then be supplying will practically equal the quantity at present being sold by coke ovens in the Ruhr to gas undertakings. A larger development is in progress in Germany, but, as has already been indicated, there are many differences in conditions between Germany and Great Britain which make the development of the utilisation of coke oven gas by the gas industry here more difficult.

It is very desirable, however, that there should be understanding and co-operation between the coke oven and the gas industries and there is more of this to-day than at any period in the history of the two industries. They are working hand in hand in the disposal of sulphate of ammonia, benzol, pitch, creosote and road tar, and there is no reason why there should not be closer co-operation with regard to gas and coke. It is this greater understanding which has resulted in the recent large contracts for coke oven gas. With still greater mutual understanding there will be further progress. The recent setting up by the two industries of a Joint Standing Committee to consider the problems affecting the supplies of gas and coke will greatly assist in this direction. Information is given in this paper which it is hoped may be of assistance to both industries. It should be understood clearly that the gas industry is not against the use of coke oven gas—what it is against is the utilisation of it at uneconomic prices and it is also against any question of compulsion.

Coke oven gas cannot be sold to other industries on terms which are not economic to those industries. The gas, being a by-product of coke production, can only be utilised on terms which are economic to the user, whoever he may be.

It is in the national interest that every effort should be made to secure the most economic use of coke oven gas. This in some cases may be found to be in steel works—particularly if modernised ovens be erected adjacent to steel works, as has been put forward frequently, and was particularly recommended at a recent meeting of the Institution of Civil Engineers by Professor Bone, of London, and Professor Louis, of Newcastle. In other cases it may be found in synthetic processes and in yet others in sales to public utility undertakings.

It is the author's opinion that there will be a growth in the quantities of coke oven gas utilised by the gas industry, particularly in the coke oven districts, but it must not be overlooked that there are many gasworks equipped with modern plant specially designed for the production of gas at the lowest cost, where the economic price which can be paid for an outside supply, after adjustment for the

items enumerated above, is such as may not be so attractive to coke oven owners as the utilisation of their gas in other ways.

It does not seem advisable in the national interest that there should be any sudden grandiose schemes for the general utilisation of coke oven gas in any particular direction; it is better that it should be developed gradually on economic lines.

RÉSUMÉ

L'industrie du gaz a eu un essort considérable sous une gérance efficace, tandis que ceci n'a pas été le cas dans l'industrie des fours à coke. Dans un avenir proche, les installations à coke en Grande-Bretagne devront être remplacées par des installations plus modernes. A l'heure actuelle, il n'y a pas beaucoup de gaspillage de gaz excessif, quoiqu'une certaine quantité ne soit pas mise tout à fait à profit. Une fois les installations à coke reconstruites, sans doute il y aura une quantité plus considérable de gaz excessif.

L'industrie des fours à coke est d'avis que les entreprises de gaz peuvent aisément payer le prix le meilleur pour le gaz et elle a suggéré que dans certaines circonstances les entreprises de gaz devraient être forcées de se procurer du gaz des fours à coke à un prix déterminé d'un commun accord ou par un arbitre L'industrie du gaz naturellement s'y oppose.

L'industrie du gaz considère que le progrès dans l'achat du gaz des fours à coke a été retardé par le manque d'appréciation par les vendeurs, des règlements statuaires qui s'appliquent aux entreprises du gaz, ces vendeurs demandant en outre un prix trop élevé.

Les conditions générales essentielles d'un contrat sont les suivantes: régularité dans la qualité et la pression et continuité d'approvisionnement, en plus d'un prix économique.

Les règlements statuaires sont énumérés ainsi que les conditions de revient qui doivent être prises en considération en déterminant les prix, les variations des besoins des consommateurs et les différentes catégories de contrats qui pourraient se faire

On démontre que les fours à coke peuvent fournir, ce qu'ils font en effet, du gaz d'une teneur satisfaisante pour les besoins urbains; que la distance probable à laquelle le gaz doit être transmis en Grande-Bretagne n'est qu'une question de coût; et que le prix économique payable dans chaque cas doit être basé sur les circonstances individuelles.

On démontre que les risques de manque d'approvisionnement sont plus grands en Grande-Bretagne qu'en Allemagne et que les conséquences en sont plus sérieuses, ce qui fait que des installations de réserve doivent être maintenues par les compagnies à gaz. Ceci naturellement doit empêcher l'utilisation complète du gaz des fours à coke par l'industrie du gaz par suite des frais survenant en relation avec la capacité continue des usines à gaz de continuer à fournir du gaz au public dans le cas où les fours à coke ne seraient pas à même de faire face aux besoins.

L'analyse est faite des entreprises de gaz statuaires suivant leur importance dans chaque conté du pays et démontre que 695 parmi un nombre total de 784 entreprises vendent chacune moins de 500 millions de pieds cubes (14,000,000 m^3).

Northampton .	6	[illegible]	2	[illegible]			1	[illegible]			
Northumberland .	4	306,002			1	590,678			1	4,337,485	6	5,234,165
Nottingham ..	10	726,341							1	2,839,600	11	3,565,941
Oxford .. .	6	241,636			1	746,555					7	988,191
Pembroke	6	136,136									6	136,136
Radnor	1	14,861									1	14,861
Rutland ..	1	27,684									1	27,684
Shropshire	[illegible]	[illegible]	1	[illegible]							8	604,638

Les cartes montrent où se trouvent les fours à coke et la région dans un rayon de 50 milles anglais (80 km.) de ces fours.

On fait la comparaison entre le gaz vendu dans ces districts et le gaz produit par les fours à coke qui ne fut pas employé pour le chauffage de ceux-ci. On montre également les entreprises de gaz de différentes importances dans huit différents districts. Ces cartes démontrent que les principaux endroits de consommation de gaz en dehors dudit rayon ont à leur disposition des moyens de transport par eau avantageux et peuvent obtenir de bons prix pour leur coke, tandis que le gaz produit par les fours à coke serait entravé par les frais de transport à grande distance.

On démontre que le gaz pour besoins industriels ne devrait pas être fourni en état cru par les fours à coke dans les régions où il y a des entreprises de gaz capables d'en fournir. Il vaudrait mieux adopter le système de laisser l'approvisionnement du gaz purifié aux entreprises de gaz qui ont déjà fait de tels efforts pour développer la vente de gaz pour besoins industriels et qui, si on leur accorde les facilités qu'elles cherchent actuellement, seront à même de vendre le gaz pour besoins industriels à des prix inférieurs, en relation plus exacte au coût de revient qu'à présent.

L'industrie des fours à coke s'efforce de s'accaparer du marché domestique pour son coke, bien que jusqu'ici ce marché ait toujours été entre les mains des entreprises de gaz: et on a démontré que si les entreprises de gaz trouvent de la difficulté à vendre leur coke du type actuel, elles adapteront leurs méthodes de fabrication de façon à pouvoir satisfaire n'importe quelle demande.

On avance l'opinion qu'il devrait se créer une co-opération entre l'industrie des fours à coke et les entreprises de gaz et que la nomination récente d'un "Joint Standing Committee" aidera beaucoup à cet effet. L'industrie du gaz ne s'oppose point à l'emploi du gaz des fours à coke, mais elle est contre son emploi à des prix non-économiques et s'oppose à y être contrainte. Le gaz des fours à coke ne peut pas être vendu à d'autres industries à moins qu'il soit avantageux pour celles-ci. Ce gaz étant un sous-produit de la fabrication du coke ne peut être utilisé qu'à des conditions favorables aux personnes et aux industries qui l'emploient, quelles qu'elles soient.

On avance l'opinion que dans l'intérêt national on devrait faire tous les efforts afin d'obtenir l'emploi le plus économique du gaz des fours à coke. Dans certains cas ceci est réalisable dans les aciéries, surtout si l'on érige des fours à coke modernes à proximité de telles aciéries; dans d'autres cas ceci pourrait se faire en l'employant à des procédés synthétiques, et en tiers lieu en le vendant aux entreprises d'utilité publique.

On avance en outre l'opinion qu'il y aura un accroissement des quantités de gaz de fours à coke utilisable par l'industrie du gaz, surtout dans les régions où il y a des fours à coke, mais on fait remarquer qu'il existe grand nombre d'usines à gaz modernes où le prix économique à être payé pour le gaz des fours à coke, après avoir ajusté tous les frais de revient, serait tel à ne pas devenir profitable pour les fours à coke.

Finalement, on avance l'opinion qu'il n'est pas expédient d'envisager de grands projets, tout d'un coup, pour l'emploi général du gaz des fours à coke pour divers buts, mais plutôt de laisser le développement se faire graduellement et économiquement.

A BRIEF HISTORY OF THE GAS INDUSTRY IN JAPAN

POWER ASSOCIATION OF JAPAN

SAKURA OKAMOTO

Paper No. G11

CONTENTS

I—THE DEVELOPMENT OF THE GAS INDUSTRY IN JAPAN

(A) The Preliminary Stage

The gas industry was introduced into Japan when the German Consul Von Adolph Reis attempted to get a franchise from the Yokohama City Authorities in 1870. His original plan, endorsed and supported by the Belgian Minister, was to erect lamp-posts along the streets, which were to be illuminated by coal gas, by a private concern. Thereupon, the City Authorities, having carefully studied the proposal, framed a policy and decided to grant the franchise to native business men rather than to foreign residents. When the interested people were incorporated, the concession was finally given to them.

The construction work was actually begun under the supervision of the French engineer, M. Pellegrin, and completed in the year 1872, and the public thoroughfares in Japan were illuminated with gas-lamps for the first time. Incidentally, it was just a year after the Gasworks Clauses Act was enacted in England. Previous to this, there was a proposal to establish a similar industry in Tokyo, but it was not realised until the year 1873. The work was also carried out under the direction of M. Pellegrin, and in 1874 the streets of the Japanese metropolis were illuminated with gas lights for the first time.

It was about this time that the dawn of the new era of Meiji was breaking in this country. Those were the days of reformation and reorganisation of all social and political systems, and anything which western civilisation might bring us in such a transitory stage naturally made a very deep impression upon the people. Gas is one of the things in which the Japanese people took a very keen interest. Its brightness contrasted strongly with the petroleum oil lights hitherto used on the public roads. But the living conditions of the people at that time could not as yet permit the utilisation of this new illumination for domestic uses, and at the end of 1877 the number of gas consumers in Tokyo city was only nineteen. It is quite natural that under such circumstances, a gas company in those days could not make both ends meet.

In 1892, a gas business which was started by the citizens of Yokohama was afterwards placed under the direction of the municipal authorities in order to push the business. It has since then remained under the municipal ownership. In Tokyo, the gas business was originally maintained by a public fund set aside as emergency savings of the feudal Shogunate government. In 1885, it was transferred to private ownership for the purpose of encouraging the further development of the gas industry.

During the following period of twenty-seven years, no noticeable progress was made in this industry, but about the beginning of the twentieth century a new impetus was given to the gas industry of the country.

In 1903 there were five gas companies and in 1908 the number was eight, in 1910 ten, 1911 thirty-three, their total capital amounting to 37,940,000 yen.

(B) The Expansion Stage

After the Russo-Japanese War in 1904-1905, just at the time when a sudden and intense activity occurred throughout all business and

industrial circles, the practical utility of gas for heating and lighting purposes was universally recognised, and with the development of other industries in this country the gas business also began to make a remarkable progress, as shown in the following table:—

Year.	No. of manufacturers.	Capital invested.	No. of consumers.	Amount of gas produced.
		Yen.		Cub. ft.
1911	33	—	—	3,700,000,000
1912	75	46,662,980	494,361	4,359,643,893
1913	75	58,355,623	599,043	5,645,907,745
1914	88	77,715,350	643,469	6,052,165,870
1915	91	81,098,885	611,007	6,224,383,966

The above table shows that the number of manufacturers increased by fifty-eight at the rate of about 175 per cent. within a period of five years:

Owing to the nature of the industry, which keeps pace with the advance of civilisation, and to the advantages which the business is assured by monopolistic contracts with municipalities or other self-governing bodies, a boom in gas enterprises became quite evident, and the highest record of the increase of the number of companies was reached in 1915. Their invested capital increased by 73 per cent. in this year as compared with 1912. In 1914, the consumers numbered 643,469, the highest record in the thirteen years ending in 1924.

The gas industry was originally intended for street lighting. The remarkable increase in its use for that purpose may be seen in the following table:—

Year.	No. of street lamps.	No. of openings for lighting.	No. of openings for heating use.	No of gas engines.
1911	—	841,014	387,802	2,089
1912	6,599	1,199,708	591,240	2,347
1913	9,094	1,454,701	768,076	2,020
1914	9,525	1,544,115	907,480	2,691
1915	9,283	1,551,861	1,040,477	1,970

(c) The Period of Depression

With the development of the gas industry, there came also a remarkable development of the electric industry in Japan. During the period of eight years from 1907 to 1914, the number of electric light consumers increased fifteen times, reaching 3,270,000 in 1914. The number of lights reached 8,420,000—roughly, a ninefold increase. The number of electric motors reached over 42,000. It

can be seen from the foregoing figures that, if compared with the record of 1915 of the gas lights, which then numbered 1,551,861, the development of the electric light business during the same period is really phenomenal.

It is quite natural that this new electric lighting and power should make a great change in the development of the gas industry. From about the year 1914 this became more evident, as seen in the following table:—

Year.	No. of street lamps.	No. of openings for lighting use.	No. of gas engines.
1915	9,283	1,551,861	1,970
1916	8,927	1,527,713	1,921
1917	8,775	1,417,872	1,703
1918	5,472	1,329,372	1,531
1919	3,860	1,217,094	1,469
1920	2,925	1,239,331	1,184
1921	2,335	1,224,776	966
1922	2,117	1,159,641	867
1923	1,654	401,995	699
1924	1,180	518,624	559
1925	1,091	609,005	497

As shown in the last table but one, the street lamps and gas engines reached a maximum in 1914, but since then they have gradually decreased year after year. If the maximum number in each case be represented by 100, the reduced number of street lamps and gas engines for 1925, as shown in the above table, would be represented by the figures 11·45 and 18·47 respectively, as compared with 1914, and those lamps and gas engines which remain are kept either for the street service for municipalities or other self-governing bodies, or as a reserve power in case of a shortage of the electric power supply.

Regarding the use of gas for lighting as set forth in the above table, this also showed a tendency to decrease gradually after 1915, until the year 1923, when the great earthquake destroyed a large part of the gas fixtures in Tokyo and its vicinity, and in 1925 it diminished to 609,005 openings only, which is a decrease to 39·24 compared with the highest record, if this latter be represented by the figure 100. Thus, the use of gas for lighting has become secondary to its use for heating, and gas for lighting is only used to meet an emergency, whenever electricity fails accidentally. On the other hand, the gas industry for the heating service has made rapid strides in its development, as was the case in civilised countries in Europe and America.

The gas industry, which received a blow both in lighting and power services by the development of electricity, was also largely affected by the economic and industrial disorder resulting from the Great War in 1914. This can be seen from the following table:—

Year.	No. of manu-facturers.	No. of consumers.	Capital invested	No. of openings for heating.	Amount of gas produced. Cub. ft.
1915	91	611,007	Y81,098,885	1,040,477	6,224,383,966
1916	88	585,593	75,163,214	1,066,866	7,070,308,367
1917	74	549,924	72,811,270	1,037,369	7,988,454,784
1918	77	505,401	75,073,003	1,035,012	9,177,957,824
1919	77	488,422	75,663,413	965,213	9,785,507,538
1920	77	492,214	83,687,583	956,401	10,361,780,980

As shown above, notwithstanding the fact that the amount of the capital invested in the gas industry increased by 2,588,698 yen, which is about 3 per cent. more as compared with the amount invested six years previously, the number of consumers showed a considerable decrease, although the amount of the total production was augmented.

During the war, the price of coal went up abnormally with encouraging business conditions. The trend of the index figure of wholesale prices was distinctly upward. Taking the price of the year 1900 as the basic number 100, it rose to 129 in 1912, 145 in 1916, and 421 in 1919. But the gas rate could not easily rise side by side with the rising prices of general commodities, because the gas business was at first started as a private undertaking, and its management was under strict supervision by the city officials, with a Compensation Contract. While the index number of coal prices rose by 245·7 per cent. in 1921 as compared with the pre-war index number of 100, the price of gas showed a rise of a little over 51·1 per cent. only.

Under such conditions, either a dissolution of the business by liquidation or an amalgamation with an electric company began to be talked over among the gas companies whose credit was not good enough to withstand their difficulties. In 1917 and 1918, there were twenty-three companies which liquidated, and eighteen which amalgamated with or which were purchased by other companies. Consequently, the number of consumers diminished to 488,422 in 1919, which is a decrease of over 20 per cent. in comparison with the highest record number in 1914. In this way, we see hard times for a while in the history of the gas industry in this country.

(D) THE PERIOD OF PROSPERITY

In the year 1920 the Great War came to an end. Needless to say, great changes have occurred in everything in the world. Of course, there was great disorder in Japanese business circles. But, as the gas industry in Japan had already gone through a long depression, it received little influence from the general post-war depression and even entered into an age of recovery.

Year.	No. of manufacturers.	No. of consumers.	Capital invested.	No. of openings for heating.	Amount of gas produced. Cub. ft.
1920	77	492,214	Y83,687,583	956,401	10,361,780,980
1921	75	502,828	89,785,967	1,009,847	10,794,453,172
1922	72	552,367	96,641,314	1,194,033	12,191,973,567
1923	72	463,746	106,181,281	396,037	11,619,096,916
1924	73	568,477	116,432,560	1,087,472	12,475,411,120
1925	73	683,087	146,296,328	1,256,178	13,830,999,811
1926	75	796,462	151,875,351	—	16,063,600,796
1927	75	838,714	—	—	—

Though there was a great set-back in 1923 caused by the disastrous earthquake in Tokyo and Yokohama, the gas industry has shown an upward development since the year 1921, until it showed in 1926 an 81 per cent. increase in the capital investment and in 1927 a 70 per cent. increase in the number of consumers as compared with the figures for 1920. This development is principally due to the settlement of the question of the cost price, and the introduction of the system of scientific management in the business, both having been thoroughly studied under the direction of the Imperial Gas Association organised mostly by the gas people. On the other hand, the advance of the standard of living and the increasing cost of fuels also assisted the rapid growth of the gas industry.

The index number of the prices of coal, wood, and charcoal used in a Japanese household is given in the following table with that of the price of gas, in order to show the rise or fall of the respective fuel matter during the past years.

Year.	Coal.	Wood.	Charcoal.	Gas.
1912	100	100	100	100
1915	101	91	88	95
1920	320	315	369	159
1921	245	296	319	158
1922	242	271	312	156
1923	241	257	313	156
1924	258	214	284	157
1925	232	173	261	154
1926	222	176	248	153
1927	238	181	259	152

Although an all-round decline in the price of fuels can be noted since the year 1920, when it was at the highest point, the prices of coal, wood and charcoal still remained at their levels of 138 per cent., 81 per cent., and 159 per cent. respectively higher than their prices in 1912, while that of gas remained at the level of only 52 per cent. higher.

Owing to this relatively small rise of the price, the demand for gas as fuel naturally has constantly tended to increase. This has stimulated the gas companies to make every possible improvement in their business management, as well as in their engineering equipments. These things have made the cost of production much lower.

As for the profit of the business, thirty-six out of seventy companies are able to pay annually more than 10 per cent. dividend; thirteen more than 8 per cent.; eleven more than 5 per cent.; four less than 5 per cent. and only six pay no dividend. The industry, as a whole, is now on the upward trend, and more new gas companies are being promoted in cities and towns. We can safely conclude that the business has now recovered and is in the prime of its development.

II—THE PROGRESS OF GAS MANUFACTURING PLANTS

The first gas generating plants which were adopted in our country were solid-ended horizontal retorts. Subsequently, owing to the necessity of meeting the ever-increasing demands for gas in large cities such as Tokyo, Yokohama, Osaka, Nagoya and Kyoto, these were replaced by either inclined retorts, vertical retorts, chamber ovens or else through horizontal retort benches with mechanical chargers and dischargers.

With the improvement of gas generating equipment and the increase of demand for gas, the water gas generator was for the first time adopted in 1902 by the Tokyo Gas Company, in order to accommodate the seasonal changes of gas loads, and also the amount of coke produced. Since that time the gas undertakings in large cities like Osaka, Kyoto, and Nagoya have begun to follow the example of Tokyo and to use water gas generators.

With the progress of the standard of living of the people at large after the World War, the demand for gas has been largely increased, and as a consequence, how to dispose of the by-products, for instance as coke, has become a hard problem to solve for the gas manufacturers. In 1924, the Kobe Gas Company imported at first the Tully system to solve this problem. In the reconstruction of

Yokohama after the great earthquake of 1923, the Yokohama Gasworks has been equipped throughout with complete gasification plants which were manufactured by the Power Gas Corporation in England. Recently, the Tokyo Gas Company has built its complete gasification plants of the German Strache and the Bamag Meguin type, which, however, are still in the course of experimenting.

We have imported almost all types of gas generators from abroad, and we have studied them all carefully and constantly to find out the ones best suited for our own use, in order to keep down gas production costs as much as possible. The result has been that we have gathered here almost the best types of all foreign makes. The following table shows the types of the gas generating equipments which were imported and which we are now using:—

Types of furnace.	No. of gas under-takings.	No. of works.	No. of retorts.	Generating capacity per day. Cub. ft.	Ratio.
Horizontal type ...	73	89	3,095	27,744,870	43·85
Inclined type ...	1	2	500	6,500,000	10·27
Vertical type ...	2	3	176	4,702,000	7·43
Oven type ...	4	7	210	6,622,000	10·47
Water gas ...	4	6	21	13,500,000	21·34
Complete gas ...	3	3	10	4,200,000	6·64
Producer ...			2		

At first we depended entirely for retort materials on those of foreign origin, but we can now supply them easily ourselves.

The first gas refining plants we used were of the English type, but in 1904 those of the German type were introduced, and since then we have made great efforts to improve them so as to make them suitable for our gasworks, and we have now the most up-to-date gas plants in our works.

As for gas purification, the Osaka Gas Company adopted an American Koppers wet purifier in 1926, while for measuring gas generated, the wet meters are chiefly used for station meters, but in some quarters the meters of the Rotary type have been introduced since 1907. The Venturi and Displacement meters are also experimentally used.

The gasholders in use are chiefly of the type of frame guided gasholders. In some quarters, spirally guided gasholders are used. The materials for construction were at first imported from England and Germany, but they are now manufactured in our country.

Stimulated by the development of the waterless gasholder in Germany, the Government Steelworks at Yawata has imported

one of 150,000 cub. ft. in 1926, and has been followed by the Tokyo Gas Company, which has imported recently two of the capacity of 2,000,000 cub. ft., and 4,000,000 cub. ft. respectively.

The following table shows the gasholders in use in 1926 in our country:—

Storage capacity of each gasholder. Cub. ft.		No. of gasholders.	Total capacity of gasholders. Cub. ft.
Above	3,000,000	6	18,500,000
,,	1,000,000	10	11,500,000
,,	500,000	9	5,400,000
,,	100,000	29	4,050,000
,,	50,000	45	2,520,000
Below	50,000	50	1,207,000
Total	—	149	43,177,000

(A) The Growth in Gas Generating Capacity

In all the gas manufacturing plants in Japan, the daily total generating capacity in 1926 reached 63,268,870 cub. ft., of which the generating capacity of the gas undertakings in the six large cities, Tokyo, Osaka, Kyoto, Nagoya, Kobe and Yokohama, was 50,900,000 cub. ft., that is, 80·5 per cent. of the total amount.

Classifying the gas undertakings according to their generating capacities, there are five companies with a daily capacity of generating gas from 10,000 to 30,000 cub. ft.; twenty-two from 30,000 to 80,000 cub. ft.; fourteen from 80,000 to 150,000 cub. ft.; twenty-three from 150,000 to 600,000 cub. ft.; and seven generate 600,000 cub. ft. or more.

Taking all the companies together, the daily generating capacity in 1921 amounted to 46,574,000 cub. ft. This represents an increase of 109 per cent. as compared with 1912. Of this daily total generating capacity for the whole country, 38,590,000 cub. ft. is for the six large cities, which showed an increase of 105 per cent. during the fifteen years since 1912. Again, the daily total generating capacity in 1926 amounted to 63,268,870 cub. ft., which is an increase of 185 per cent. compared with that of 1912. Of this daily total, 50,900,000 cub. ft. belonged to the six large cities, showing an increase of 171 per cent.

During the year 1926, 13,950,751,183 cub. ft. of coal gas, 1,325,551,109 cub. ft. of water gas, 714,101,496 cub. ft. of mixed gas, 56,471,452 cub. ft. of producer gas, and 16,725,556 cub. ft. of natural gas were produced.

Needless to say, the cost price of gas varies according to the location of the plants, the price of coal for use and the market prices

of by-products for sale. If we do not take in the expenses arising from the coal and the fuel used, the average manufacturing cost (such as salaries, miscellaneous charges only) will differ according to the scale of gasworks as shown in the following table:—

	Gasworks capacity per day. Cub. ft.	Manufacturing cost per therm.
From	10,000 to 30,000	3d. 05
,,	30,000 to 80,000	2d. 64
,,	80,000 to 150,000	2d. 30
,,	150,000 to 600,000	2d. 19
,,	600,000 to above	1d. 72

(B) THE KINDS OF COAL USED AND THE QUALITIES OF GAS PRODUCED

As our coalfields are chiefly located in Kyushu and Hokkaido, gas undertakings in the north-eastern parts of Japan are solely using the Hokkaido coal, while in the south-western parts the Kyushu coal is used. The Kyushu coal contains much sulphur, and therefore it is generally used mixed with the Hokkaido coal, which has less sulphur and contains a relatively large proportion of volatile matter. The Yubari coal of Hokkaido is chiefly used for the manufacture of gas. Besides that, the Shinyubari, the Oyubari, the Mojiri and the Utashinai coal are also in use for the same purpose.

Among the Kyushu coals, the Mannoura, the Matsushima and the Sakito are popular, while the Takashima, the Tadakuma, the Shyakano-o, the Namazuda, and others are pretty well known to gas manufacturers. For the purpose of obtaining foundry coke, the Kaipping, the Poshan, the Pen-hsi-hu, and the Yi-hsien coal of China, and the Hongay coal from Indo-China are used as a mixture in the chamber oven. For the purpose of complete gasification, the Fushun coal of Manchuria is preferably used.

The following table shows an analysis of the constituents of the principal coals used for the manufacture of gas in our country:—

Name of Coal.	moisture per cent.	Volatile matter per cent.	Fixed carbon per cent.	Ash per cent.	Sulphur per cent.
Yubari ...	0·58	42·48	48·67	8·85	0·38
Mannoura	0·73	39·28	50·23	10·49	1·13
Matsushima	0·96	41·14	47·82	11·04	1·92
Sakito ...	0·45	40·55	47·38	12·07	2·30
Takashima	0·43	37·40	55·55	7·05	0·91
Kaipping ...	0·53	31·03	51·46	17·51	1·53
Poshan ...	0·22	22·25	65·41	12·34	0·62
Pen-hsi-hu	0·69	18·26	66·27	15·47	1·02
Yi-hsien ...	0·53	28·48	58·97	12·55	0·87
Fushun ...	3·36	41·05	48·80	10·15	0·85
Hongay ...	1·12	10·90	80·75	8·35	0·63

The gasworks generally use powdered coal, although a few use the run of mine coal. Gasworks operating on a small scale generally use only one kind of coal, while those working on a large scale use more than two kinds of coal mixed together proportionally, in order to obtain good domestic coke and a proper ratio of gas components. The price of coal, of course, varies according to the location of the gasworks, but on the average it runs from £1 to £2 sterling per ton.

Before the enactment of the Gas Industry Law, although we did not concern ourselves with the constituents and the calorific value of gas, it is said that until 1912 gas of good quality having a calorific value of more than 500 B.Th.U. was supplied. As a result of the World War, the price of coal rose suddenly in our country as in other countries, and owing to the necessity of economising coal the calorific value was gradually decreased.

The Gas Industry Law, which has been enforced since October 1925, has established a regulation that an engineer in charge of a gasworks must qualify himself by passing the government examination. The law has also restricted the contents of sulphur (less than 5 gm. in 10 cub. metres) and ammonia (less than 2 gm. in 10 cub. metres) in gas, and required the gas companies to declare the minimum amount of the calorific value as well as the pressure of gas to be supplied.

The following are the thermal value and pressure declared by the gas undertakers, approved in December 1927 by the Government:—

CALORIFIC VALUE.

	Highest B.Th.U.	Lowest B.Th.U.	Average B.Th.U.	Remarks
In the six great cities	415 (3,700 cal.)	404 (3,600 cal.)	406 (3,620 cal.)	(Yokohama excepted).
In other places	449 (4,000 cal.)	337 (3,000 cal.)	371 (3,310 cal.)	(Natural Gas excepted)

PRESSURE.

	Highest.	Lowest.	Average.	Remarks.
In the six great cities	$1\frac{9}{16}$ in. (40 mm.)	$1\frac{1}{2}$ in. (38 mm.)	$1\frac{17}{32}$ in. (38·8 mm.)	(Yokohama excepted)
In other places	$2\frac{3}{8}$ in. (60 mm.)	$1\frac{1}{2}$ in. (38 mm.)	$1\frac{18}{32}$ in. (40·1 mm.)	(Natural Gas excepted).

An average calorific value of the gas supplied is summarised in the following table from the data obtained during the year 1926:—

Calorific value.	No. of gasworks.	Percentage of total gas manufactured.
Over 500 B.Th.U. (4,450 calories)	2 (supply by purchase)	0·4 per cent.
Over 450 B.Th.U. (4,005 calories)	11 (one of them is supplying by purchase)	18·0 per cent.
Over 420 B.Th.U. (3,738 calories)	24	66·3 per cent.
Over 400 B.Th.U. (3,560 calories)	19	6·8 per cent.
Over 380 B.Th.U. (3,382 calories)	14	2·5 per cent.
Less than 380 B.Th.U. (3,382 calories)	21	6·0 per cent. (Natural Gas excepted).

The fact that the calorific value of the gas supplied by the undertakings here is relatively low, as compared with Europe and America, can be attributed to the force of circumstances arising from the failure of the gas rate to keep pace with the remarkable rise in the price of coal subsequent to the Great War. Although the entire industry is fully awake to the need of improvement in this direction, under the present rates charged immense difficulties stand in the way of realisation, since it is only quite recently that the gas industry has been put on a firm economic basis, while the amount of gas consumed per meter is so small that the capital invested seems disproportionately large.

However, as the demand for gas increases and the amount set aside for reserves and depreciations grows larger through the united efforts of those engaged in the industry, it can be confidently anticipated that the calorific value of the gas supplied will attain a much higher standard, and, consequently, the existing equipment will be used to its full capacity of efficiency.

(c) BY-PRODUCTS

The ratio of coke and coal tar produced to the amount of the coal used in coal gas plants differs according to the type of the oven and the kind of coal used; but in general, the ratio of coke is from 60 per cent. to 70 per cent. and coal tar about 5 per cent. to the amount of coal used.

The amount of coke and coal tar produced in the last five years is as follows:—

Year.	Coke.	Coal Tar.
1922 ...	1,104,850,828 lb. (493,362 tons) ...	9,162,339 gal.
1923 ...	1,051,971,971 ,, (469,733 tons) ...	8,559,611 ,,
1924 ...	1,096,727,394 ,, (489,290 tons) ...	9,417,383 ,,
1925 ...	1,141,176,893 ,, (509,585 tons) ...	10,072,102 ,,
1926 ...	1,237,829,540 ,, (552,738 tons) ...	10,833,946 ,,

In our country when the gas industry was still in its infancy, coke and tar were dumped into rivers or into the sea as useless. However, with the development of other industries, they have come to be made use of in many different ways. Recently, the need for smokeless fuel has been felt keenly in urban districts, and coke is very much in demand as fuel in houses as well as in factories.

Coal tar is used chiefly for paving roads, in addition to its uses as a component of paints or various fuel substances. The large gasworks, such as those in Tokyo, Osaka, Nagoya and Kobe, use a tar distillation process to extract such components as benzol, naphtha, creosote oil, naphthalene, carbolic acid, pitch, and so forth.

Although there were a few gas companies which began to make some of the dyestuffs and chemicals during the World War, all of them have ceased to make them now, except the Tokyo Gas Company, Ltd.

The manufacturing of ammonium sulphate has been started since 1901 in our country, and the plants for this purpose were built in the large gasworks. But the total amount produced by the gas companies alone in 1926 was only 4,529 tons, while the total production in the whole country was 147,629 tons.

III—THE DEVELOPMENT OF THE GAS DISTRIBUTION SYSTEM

The low-pressure system of distribution has been uniformly adopted by small gas companies, since the gas industry was introduced in Japan. The use of the high-pressure system for distribution has been necessitated by the increase in the amount of gas supplied, together with the expansion of the territory served.

The Nagoya Gas Company in the city of Nagoya installed high-pressure distribution equipments in 1909. Since then, it has been using them along with the low-pressure distribution equipments installed before. The Kyoto Gas Company in the city of Kyoto and the Chiyoda Gas Company in the city of Tokyo have adopted high-pressure distribution systems from their very beginning. As they have shown very satisfactory results, many other large companies have followed their example.

At present, there are five companies only which employ exclusively the high-pressure distribution system. Some companies distribute gas at high pressure either to their station gasholders or to their outlying supply district, while others use both high and low-pressure distribution systems together.

For laying mains, the location and the depth are stated by the High Ways Act, which has been in force since 1921. The pipes for mains are chiefly constructed of cast iron manufactured in Japan, but we also use steel pipes in some places occasionally. In jointing pipes, steel pipes are joined by welding or caulked with lead, while cast-iron pipes are joined by lead or cement.

The American black and galvanised wrought-iron pipes and their fittings are chiefly used for service. But recently Japanese-made malleable iron fittings are more in use.

The house pipings (those less than three-fourths of an inch in diameter) are chiefly of lead, and of wrought iron.

At the beginning of our gas industry, consumers' meters were all imported from abroad. With the growth of the gas industry, however, meters of home-manufacture are now generally in use. At present, the normal size of meters in use is of the dry 3 to 5 light type, but there is a tendency to require a larger average size of meter.

Gas meters, like other instruments of measurement, are under the control of the Government Regulations for Weights and Measures, in accordance with which they are subjected to an official examination once every five years.

Consumers are responsible for the installation costs for service and house piping, while gas meters are usually supplied by the gas companies at a certain monthly charge.

IV—VARIETIES OF GAS APPLIANCES

Along with the changes in the use of gas, gas appliances have also undergone many modifications. Owing to the differences between the food and the mode of living of the Japanese people and of Europeans and Americans, gas appliances have had quite naturally to be modified according to the requirements of the people.

When the gas lamp was introduced to Japan for the first time, the mantle and its accessories came with it at the same time. Since then, the Japanese makers have become able to supply their own goods in the market. As has been seen already, gas once attained an important place in the lighting business, but the development of the electric industry affected its growth very unfavourably. The manufacturers of gas appliances also suffered a check in their business, except possibly in making such appliances as ring burners or rice cookers designed to meet the local demand.

Of late, gas is being used more and more for cooking in cafés and

restaurants, and the good cooking ranges of foreign make are very much welcomed. Instantaneous water-heaters have been imported here since about 1905, and are now commonly used by barber shops, hair-dressers, restaurants, and others. For the central heating of an office or a private house, gas has not been largely utilised as yet, because the construction of Japanese houses is not suited to this system, though small gas fires are now very popular. A few gas refrigerators were imported from Germany and the United States quite recently, but they are not yet in large demand.

With the increasing demand for gas for industrial uses, many kinds of appliances make their appearance in the market, and it is noticeable that those superior in quality and efficiency find the readiest sale.

V—THE FUTURE OF THE GAS INDUSTRY

The majority of the Japanese people dwell in low wooden houses and sit on mats and use charcoal for heating and cooking as a common fuel in their houses. Besides, their primitive life and cheap labour make their living expenses very low, consisting of rough food and humble clothing. The expenses for lighting and heating amount, according to the annual statistics of 1927, to only 17·2 per cent. for an average salaried man, and only 19·8 per cent. for a labourer, of the house rent, which itself is very small as compared with the expenditure on foods and clothing.

Although the gas industry has made a considerable development in these days, the number of households using gas is only 13·5 per cent. of the total number of households in the territory of a gas company on an average, and the amount of consumption per meter is 18,075 cub. ft. a year. If the amount of gas used for industries is excepted, the amount per meter will be less than 10,000 cub. ft. a year, which is at the rate of about 2,000 cub. ft. a person. Furthermore, the number of consumers per mile of gas main is 160 on an average throughout the country. Even in the six largest cities there are only 184 consumers per mile on an average.

Taking such things into consideration, the gas business in Japan may be said to be still in its infancy, although the future of the industry is full of bright promise. As a matter of fact, the number of consumers and the volume of consumption are steadily increasing. According to the census of 1925, 55 per cent. of the population in the country is concentrated in cities with populations of over 5,000. The increase of the urban population will assuredly bring a much

better business to gas undertakings. Large buildings which will be built on an improved city plan will also cause a considerable increase in the demand for gas.

Gas for industrial uses is still in an early stage of development. In 1926, there were two gas manufacturers over 40 per cent. of whose output was consumed for industrial purposes; four, over 30 per cent.; three, over 20 per cent.; and twenty-two, over 10 per cent. only. It will be seen that the business of industrial gas awaits future development.

And all the time, the gas undertakings have done their utmost to improve their business, to make its financial foundation steady and to set aside as much as possible for reserves and to meet depreciation. In 1926, funds for reserves and depreciation were set aside at the rate of 4·8 per cent. to the total of the fixed capital of the industry. Naturally these have contributed much to the development of the industry. For example, the amount of the fixed capital invested for making gas of 1,000 cub. ft. dropped to 8.22 yen (16s. 5d.) in 1925 from 10.09 yen (£1 0s. 2d.) in 1921, which is a decrease of 18 per cent. during the four years.

In short, it can be reasonably said that the gas industry of our country is now on a prosperous and sound basis.

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EXPERTS

1. Dr. Y. Oshima, President of the Fuel Research Board of the Government Department of Commerce and Industry.
2. Dr K. Kurihara, Professor of the Meiji Technical University at Tobata, Kyushu, Japan.
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ZUSAMMENFASSUNG

Es sind schon 58 Jahren vergangen, seit die ersten Gasunternehmungen in Japan entstanden sind. Anfänglich hat man das Gas nur zur Strassenbeleuchtung benützt, aber durch den Fortschritt der allgemeinen Zivilisation fand das Gas auch zur Hausbeleuchtung, bei Kraftmotoren und dann schliesslich zu verschiedenen Heizzwecken Verwendung, und so hat die Gasindustrie in Japan sich ziemlich folgerichtig entwickelt, wenn auch natürlich schwankende Übergange vorkamen.

Während dieser Fortschritte wurden die besten ausländischen Gaseinrichtungen durchstudiert und jetzt sind wir im Stande, die meisten Gasanlagen, Leitungsröhren, Formstücke, Gasmesser u.s.w. im Inlande selbst anzufertigen.

Obwohl jetzt noch verschiedene neue Modelle von Gasverbrauchsapparaten eingeführt werden, so erfreuen sich doch die den besonderen japanischen Verhältnissen angepassten, hier gebauten Gasheizapparate, nämlich speziell konstruierte Reiskocher und ringförmige Bunsen (Shichirin), allgemein grosser Beliebtheit.

Was nun den Gasverbrauch anbetrifft, so zeigt die neueste Statistik, dass nur 13,5% sämtlicher Haushaltungen mit Gas beliefert werden, und dass das jährliche Verbrauchsquantum pro Haus durchschnittlich 18075 Kubikfuss beträgt. Wenn man von dieser Zahl den Verbrauch für industrielle Zwecke abzieht, so geht sie auf ungefahr 10000 Kubikfuss zuruck. Diese statistische Zahlen lassen leicht erkennen, dass für kommende Zeiten noch grosse Anwendungsgebiete vorhanden sind, und dass der Gaskonsum noch weiter gesteigert werden kann, besonders deshalb, weil die Preise anderer Brennmaterialien für Hauszwecke verhältnismässig hoch sind. Ausserdem ist bemerkenswert, dass neuerdings auch die Industrie sehr bemüht ist, Gas als Heizquelle zu verwenden.

In dieser Erwartung sind die Japanischen Gas-Unternehmen weiter bestrebt, durch ökonomische Feststellung der Produktions-Kosten, rationelle Verwaltung, mässige Verzinsung und Anhaufung genugender Reserven sich weiter zu entwickeln.

Darum sind die Unternehmungen auf feste Fusse gestellt und bereit, der kommenden zweiten Entwickelungs-Periode mit Aussicht auf guten Erfolg entgegenzusehen

COKE SCREENING

THE JOINT FUEL COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS, THE SOCIETY OF CHEMICAL INDUSTRY, THE COKE OVEN MANAGERS' ASSOCIATION AND THE INSTITUTE OF FUEL

W. S. EDWARDS

Paper No. G12

CONTENTS

GENERAL REMARKS

Coke, the one time "Cinderella" of the fuel family, has lately obtained a position of such importance as to cause engineers to devote much more time and attention than hitherto to the problem of producing a scientifically thought-out system of machinery for grading and screening this material.

The necessity for producing fuel, for both industrial and domestic uses of a higher grade and quality than ever before, has been forced upon the industry somewhat rapidly by the economic position brought about due to the high cost of coal, of labour and of freight. These circumstances have given an impetus to research and invention along avenues which hitherto did not seem to offer sufficient attraction to those engaged in the chemical and engineering branches of the industry. In the larger modern by-product works and gas undertakings, it is found that in order to command satisfactory prices for the coke produced from the many thousands of tons of coal carbonised daily, it is necessary to adopt new and scientific methods of screening and grading in order to meet the exacting demands of to-day.

The rapid increase in the use of small coke-fired domestic hot-water boilers, the steady increase in the adoption of central heating for large buildings, office blocks and institutions, the wider use of properly graded coke in metal-working trades, has afforded an outlet hitherto undreamt of for this by-product of coal, which was formerly looked upon askance excepting as a fuel for the blast furnace, foundry cupola, and on the domestic side for the hot-house and the meeting-room stove.

The screening of coke would at first sight appear to be a simple matter, depending merely on the obvious fact that an individual particle will drop through a hole larger than itself but not through a hole smaller that its least dimension. In the application of this simple principle a multitude of difficulties and details have to be encountered.

It will be the object of this paper to endeavour to set out some of the ways in which this important problem has been approached during recent years, and which have met with some measure of success.

Nature of Coke

It is unfortunate that coke has to be handled, screened and stored, for the reason that its physical character resembles that of an imaginary material having some of the leading characteristics of *an egg, an emery wheel and a sponge.* The greatest care therefore is required to reduce breakage to a minimum, and the design of all machinery for coke handling must have special regard to the rapid wear which will take place in the parts with which the coke comes into contact.

The properties of coke are generally understood but not always appreciated, resulting in too niggardly a policy in regard to the extent and type of apparatus to be employed and the continued use of crude methods possessing fundamental faults which render anything like a high-class product impossible of attainment.

Again, coke, owing to its structure being full of pores and cavities, allows of large pieces becoming filled with smalls and fines which do not separate out until after the large coke has found its way to the storage heap or truck as the case may be, unless this fact is fully recognised in the choice of apparatus used.

Screens in General

Various types of screens have been developed, such as the ***reciprocating*** type, designed primarily for coal, the ***revolving*** screen

originally designed for sand, stone, shingle and gravel, and the *vibrating* or *impact* type of screen evolved for the very fine screening of ores in metallurgical work, salt plants, and fine carbon screening. All of these screens have been used with little or no adaptation to suit the very special properties of the material, coke.

Latterly, however, the importance of the subject has created an interest on the part of manufacturers which has resulted in apparatus being placed upon the market which are greatly in advance of the somewhat primitive methods hitherto in use. The use of such machines is doing much to improve the product, which improvement is reacting in the way of increased demand for coke in many directions.

Special Points in Lay-out

The first thing of importance in considering the design and lay-out of a coke screening plant is to realise fully the behaviour of the coke itself throughout its passage through the plant.

From the time the coke is formed in the ovens or retorts to the time it is ultimately put to use, some breakage, and consequently breeze, is produced every time it is moved. When the coke leaves the oven or retort, breakage occurs (this is worst with horizontal ovens or retorts), and further breakage takes place when the coke is fed on to the system of conveyors which carry the coke to the screening plant.

Except in the case of a properly designed belt conveyor, more breakage takes place during passage on the conveyor itself, and in the case of some of the drag-link and scraper types of conveyors this breakage is very severe indeed. At the point at which the coke leaves the conveyor and enters the screen, breakage occurs. During the actual process of screening itself, more breakage occurs varying very greatly with the type of screen employed. When finally delivering the coke into the storage bin, pile, or into railway wagons, breakage also occurs. All these breakages, therefore, have to be realised fully and carefully studied when planning the installation of any screening plant.

Generally speaking, the greater the quantity of coke to be dealt with in a given time, the easier the problem becomes. In small works where the amount of coke produced is dealt with in quantities of 15 to 20 tons per hour, something in the nature of a compromise has to be adopted to keep down the capital cost within practical limits.

When planning out the most suitable arrangement of plant it is essential to have a clear definition of the quality and character of the coke to be treated, namely, whether *hard, fingery, soft, dry or moist.*

A *hard* coke is very lively and bounces at points of delivery into shoots and screens, and is very destructive of all parts with which it comes into contact. A *fingery* coke is very troublesome in plugging up the larger screens, and causing fouls in bucket elevators should a restricted lay-out render the introduction of elevators unavoidable. A *soft dry* coke is easier to screen but tends to make much breeze and needs the greatest care to minimise breakage. A *moist* coke is more difficult to separate and tends to plug the fine screens.

The number and size of the different grades required will have to be determined. A careful analysis should be made by hand-screening to ascertain the proportion of the various sizes which may be anticipated.

Types of Screens

Some of the more widely known types of screens which are in modern use for screening coke and with which the author is familiar will now be described.

Cylindrical Revolving Screen. This form of screen retains favour, and is probably used more than any other in spite of many faults and disadvantages from the standpoint of screening.

It is a convenient machine from a mechanical point of view. The speed is slow, there is an absence of vibration, and the screen lends itself very well to a compact arrangement of storage bins, but it depends for its screening action on the same principle as is employed on the revolving tumbler used for knocking the sand out of small castings in the foundry, the same principle as the tube mill which is used for grinding—and the same principle which forms the basis of the well-known "Bradford Breaker" so largely used in the United States for breaking coal.

The rotary screen will give an evenly-sized product, but it must be remembered that only a proportion of the ultimate smalls and breeze were present when the coke entered the screen, a large amount having been produced by the tumbling and grinding action of the screen itself. Furthermore, the rotary action of the screen throws the larger pieces to the bottom of the charge, thereby interfering with the passage of fine particles through their respective openings When in operation only about 20 per cent. of the total area of this

type of screen is active. It is not a successful screen when handling wet coke, and the maintenance and renewals of the screening medium are usually heavy.

Revolving Disc or Cataract Grizzley. One of the most efficient, and withal the gentlest, types of screen for coke is that known as the cataract grizzley which consists of a nest of revolving serrated discs mounted on parallel shafts carried between fixed side frames, the discs being so interspaced with one another and so ordered in the succession of their speed as to give almost perfect screening with the absolute minimum of breakage. This machine is rapidly gaining favour as a primary screen for removing the large coke.

The principle of this type of screen is well illustrated by Fig. 1, from which it will be seen that the "oversize" is carried gently over the tops of a succession of discs whilst the smalls fall through with a total absence of crushing action.

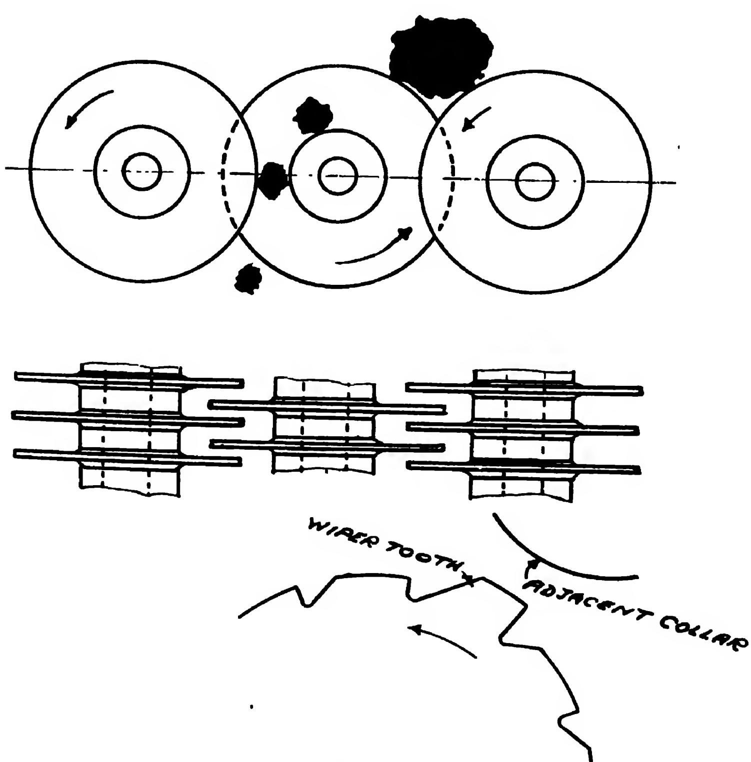


Fig. 1.

Principle of the Rotary Cataract Grizzley.

It will be noted from the illustration that the effective area of the screening openings is most ingeniously secured by the overlapping of specially spaced discs combined with a set relation between the periphery of the discs and the outside diameter of the collars between them, which collars thus perform the double service of spacing the discs and forming the third side of a square representing the mesh if it may so be termed. The fourth side of this square or mesh is formed by the periphery of the disc on the adjacent shaft which, when the screen is in operation, keeps all but the "through" screened coke in lively agitation, lifting the semi-large lumps and carrying them over on to the next set of discs.

Any pieces which may have a tendency to remain and "blind" the opening over which they lie, though not able actually to fall through, are assisted either out or through at every revolution by what is known as a "wiper" tooth. This "wiper" tooth is the one long tooth provided on each disc, the purpose of which will be readily recognised when it is seen that it fills up the screening mesh at each revolution, just clearing the spacer collar, and either lifts out or pushes through any lingering or refractory pieces which refuse to clear themselves.

This type of screen is often used as a preliminary scalper for removing all but the largest size of coke, the "throughs" being afterwards separately screened into various sizes on other types of screen. It handles the coke smoothly and gently, only agitating and turning over the lumps sufficiently to free them from entrapped smalls and breeze without grinding and knocking them about. It has a surprisingly high capacity in proportion to the space it occupies and can be usefully employed for all sizes above 1½ in.

Examples of the use of these rotary grizzley screens in combination with other screens, as installed in recent years in coke screening plants in this country, will be quoted and illustrated during the course of this paper.

The Jigging Shaking Screen. This is a development of the well-known colliery screen, and, whilst possessing the advantages of cheapness and compactness, is easily plugged up and roughly handles the coke, causing a lot of breakage and consequently smalls and breeze. The power cost is high and the maintenance comparatively heavy.

The Balanced High-speed Vibrating Screen. This type of screen of which there are a good many varieties on the market, can be designed so as to be practically free from external vibration. It has a large capacity with small power consumption and good and

effective screening in every square inch of surface, and also possesses the "kick" so necessary to work off damp breeze from moist coke and prevent clogging and plugging of the screening medium.

Several makes of these vibratory screens exist, all based on the same fundamental principle, in that they depend for their functioning on the oscillation of a fixed screen surface, generally of square wire mesh and occasionally, though not often, of a perforated plate. The several types of vibratory screens as a rule differ only in the intensity of their vibration and the method of mounting the screen plates, and any one type of such screen may be either of single or the double-deck construction.

The oscillation is in practically all cases achieved by the use of the principle of the eccentric, although its speed and method of application differ according to the make of the screen and the duty required of it. Generally speaking, the application of the eccentric for oscillating these vibrating screens may be broadly divided into two methods, the straight-throw eccentric sheave or the eccentrically balanced weight or roller. The first is more commonly used for rough screening and runs at a comparatively slow speed whilst the second is used for very fine screening and runs at a much higher speed From this it will be seen that the range of screen plate movement varies from an oscillation practically amounting to a displacement throw up to what can only be described as a vibration; in fact so finely vibrated are some makes of screens that the noise of their vibration is little more than a hum. The construction of this type of screen, and the method of mounting the screen plate, frame depend almost entirely on the speed at which the screen is designed to work.

The range of size of material dealt with by vibratory screens varies from about 3 in. cube down to dust, so that an almost infinite variety of screening product may be extracted by their use provided the appropriate size of mesh plate is attached. The capacity of a vibrating screen for coke may vary from as high as 40 tons per hour down to a few tons an hour, that is, taking the "overs" and the "throughs" together and the number of screens and the degree of oscillation or vibration, and the size of mesh plate to be employed in any one screening plant or battery depends entirely on the range of products required of the plant

Combinations of Different Types of Screens

The various types of screens described heretofore are applicable where the quantity to be handled will justify a carefully planned

lay-out involving considerable capital outlay. In most modern coke plants the whole of the screening is effected by a combination of a rotary grizzley screen working in conjunction with one or more single or double-deck vibratory screens, as will be seen during the description of several of these plants which will be given later.

In the case of small works, where the total coke produced is in the neighbourhood of only 6 or 8 tons per hour, it is necessary to fall back on plant of cheaper and less ambitious character, and at the same time to be content with results which are a good deal inferior.

For this reason, where the carbonising plant consists of a number of small units, it is well to consider the centralisation of the whole of the *coke screening, cutting and grading* in one conveniently suitable central plant, which will enable advantage to be taken of the more highly developed and efficient machines which are now available, but which for the most part range in capacity from 20 to 50 tons per hour.

For quite small plants a fixed-bar grizzley, preferably of the "cascade" type with taper section bars, may be used to take out the "oversize," the remainder being passed on to a two or three-stage revolving screen. By taking out the large lumps first, the production of breeze in the revolving screen is minimised to a considerable extent.

Multiple-Deck Screens

If the coke is of a moist nature it will probably pay to install a double-deck vibrating screen for the smalls and fines.

It may be well to mention here a difficulty which arises when employing double or treble-deck screens (Fig. 2). To secure the best results from a vibrating screen it is usual to provide for some adjustment in the amplitude of the vibration or the number of vibrations per minute, or both. In the case of a multiple-deck screen it seldom happens that the adjustment which has been found for one deck is correct for the other, with the result that a compromise has to be made which gives inefficient results.

Another difficulty with the multiple-deck screen is due to the fact that the bulk of the "throughs" from the preceding deck are taken out on the lower two-thirds of the screen, with the result that the first part of the "under" screen gets very little to do. Fig. 3 will make this point clear.

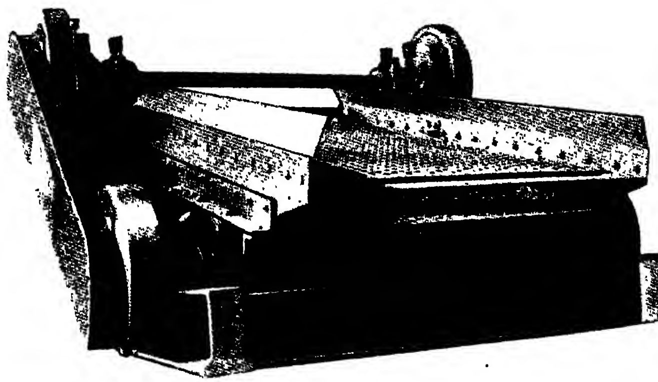


Fig. 2.

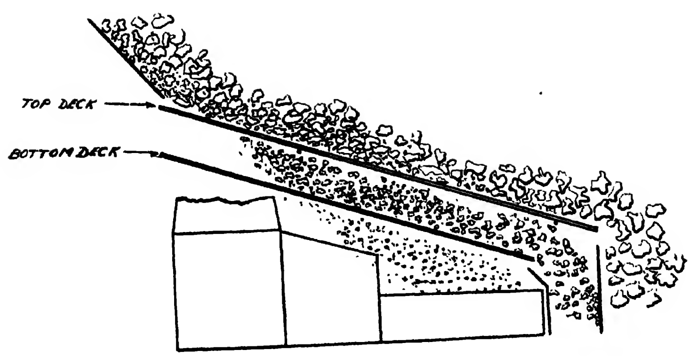


Fig. 3.

Multiple Deck Screens.

Handling Coke after leaving Screens

After the coke leaves the screen, the problem of discharging to bins, railway wagons, lorries or stock pile needs careful study.

If the coke is dropped into deep bins an enormous amount of breakage takes place when the bins are low or empty. Furthermore, the coke tends to segregate, the larger lumps rolling down the side of the heap and the fines and dust forming a pocket in the middle. Spiral anti-breakage shoots are sometimes adopted, but the wear and tear on them is excessive. Inclined bins make an excellent arrangement (see Fig. 4), the coke having little or no drop but merely sliding down the side of the bin and afterwards quietly rolling down the side of the pile.

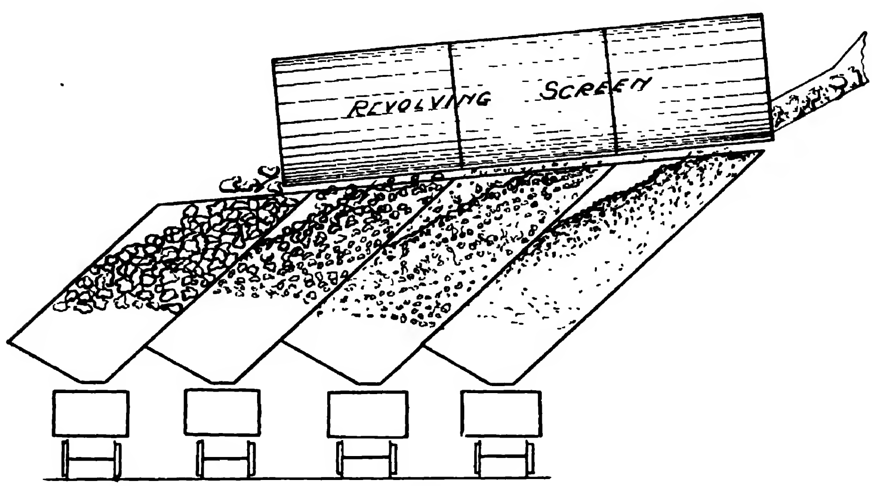


Fig. 4
Inclined Storage Bins

In spite of all precautions, a certain amount of breeze will accumulate in large storage bins, so that some arrangement of bar grizzley in the delivery chutes (Fig. 5) is quite usual. To secure the best results a vibrating screen mounted on travelling wheels so that it can be moved from outlet to outlet can be installed on either side of the bin.

Disadvantages of Over-Rating Screen Capacity

A word should be said about over-rating. When selecting screens or a system of screens for the preparation of coke, it is quite common only to specify to the manufacturer the tonnage per hour to be dealt with and the maximum size of the throughs, with the result that a

selection is made from a number of different manufacturers, all of whom offer a machine to deal with the specified tonnage and pass smalls under a certain mesh. In a good many cases in order to meet competition, a screen is put forward which, to handle the tonnage, is loaded far too heavily to give efficient screening.

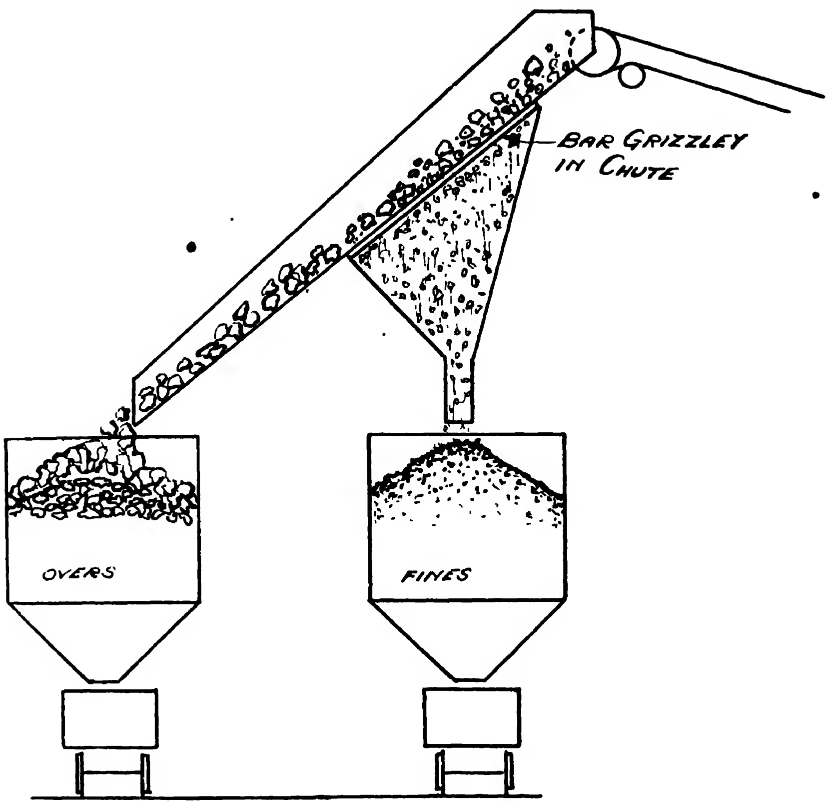


Fig. 5.
Bar Grizzley for rescreening.

For practical purposes, the "oversize" leaving a screen should not be found to contain more than 5 per cent. of "undersize" when taken straight off the screen, and not after the coke has passed through the coke bin. To secure freedom from anxiety on this score, and to obtain smoother working, it is well to allow some margin over manufacturers' figures, which quite naturally do not err on the side of modesty. *When installing new plant for preparing coke for the modern market it pays to be liberal in design. The demand for properly-sized coke is growing more exacting every day, and higher prices are paid without demur for a first-class product.*

"Up-over" versus "Down-over" Systems of Flow of Coke

Before proceeding to describe one or two typical plants of modern design, a word in general about what in some parts of the country is referred to as the "up-over" and "down-over" system of coke screening may be of value.

The elementary system of screening which followed on the lines of the ordinary colliery pit-head screening plant is the "up-over," where the whole of the material is passed over a succession of screening mediums until the whole of the smalls have fallen through the screen plates or mesh and such of the large coke as remains intact after a very trying journey passes out at the end of the shaker or revolving screen into the bins.

To secure the best results, there is no doubt that the "down-over" system is much more effective in principle. It consists of repeatedly taking out the "oversize" and re-screening the "undersize," thereby ensuring that each size is separated at once without having to be shaken or rolled about with the subsequent sizes until they have been finally disposed of.

Examples of Screening Plants

Having referred briefly to some of the more modern appliances used in connection with coke screening, a description of one or two examples of plants, it is hoped, will show the trend of modern design. The term "trend of design" is purposely used because the new coke situation has developed so rapidly that there has not yet been time for manufacturers and users to co-ordinate in a proper manner their ideas in regard to this important subject.

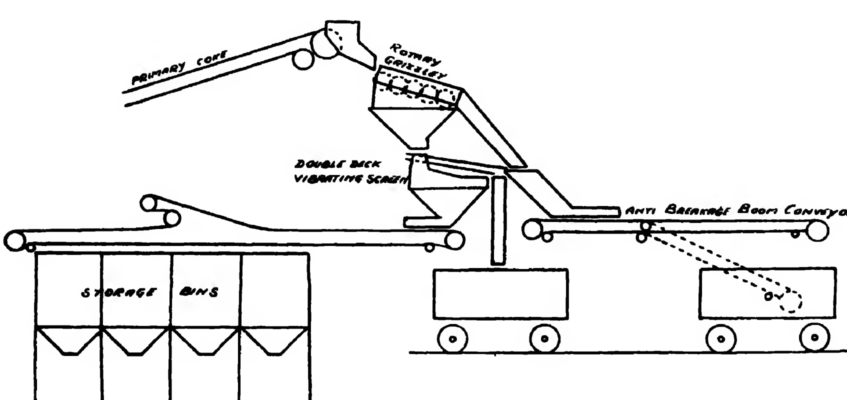


Fig. 6.
Screening plant for three grades.

A typical arrangement of coke screening plant, of which there are several in operation in the north of England, is that shown by Fig. 6, from which it will be seen that the coke is drawn from the wharf by means of an inclined conveyor and delivered direct on to a rotary grizzley which separates the large coke and delivers it direct by means of a cross conveyor and a hinged anti-breakage boom conveyor into wagons.

The "throughs" from the grizzley are deposited direct on to a vibrating screen, which divides them into two separate sizes, the larger of which is returned into the large grizzley "scalped" coke and into the wagons. The small product from the vibrating screen is taken up by means of an inclined conveyor and delivered into a storage bunker.

This arrangement, whilst typical of the general run of plant at present in use, is necessarily varied in its arrangement to suit the particular needs of the user and the lay-out of the main plant on the site. In some cases, the whole of the small coke from the grizzley may be screened into two or more sized products and stored in separate bunkers.

Another plant, which is now being installed in the north of England, has its screening arrangements arranged in two separate and distinct stations, one for rough scalping and the other for fine screening. See Fig. 7.) These stations are separated at some considerable distance from each other, and are connected by means of a belt conveyor.

Coke is delivered from the wharf on to a belt conveyor, which carries it along and up into what is known as the furnace coke or primary screening house, where it is passed over a rotary grizzley which removes all but the large size coke. The large coke is discharged from over the grizzley on to a shaking feeder which delivers it on to one or the other of two short cross-belt conveyors feeding into lines of wagons on two tracks. The smaller coke which passes through the grizzley discs is passed directly on to a long belt conveyor which conveys it to the fine or secondary coke screening station.

Inside this secondary coke screening station is a battery of three vibrating screens arranged in series with two short interconnecting conveyors. Here the small coke is separated into four distinct sized products, varying in their individual size according to the size of mesh plates fixed to the screens, the resultant "overs" from each of the first two screens being delivered into bins, whilst the "throughs" are passed on to the short conveyors. The two products from the last of this series of three screens are delivered into the last two of the

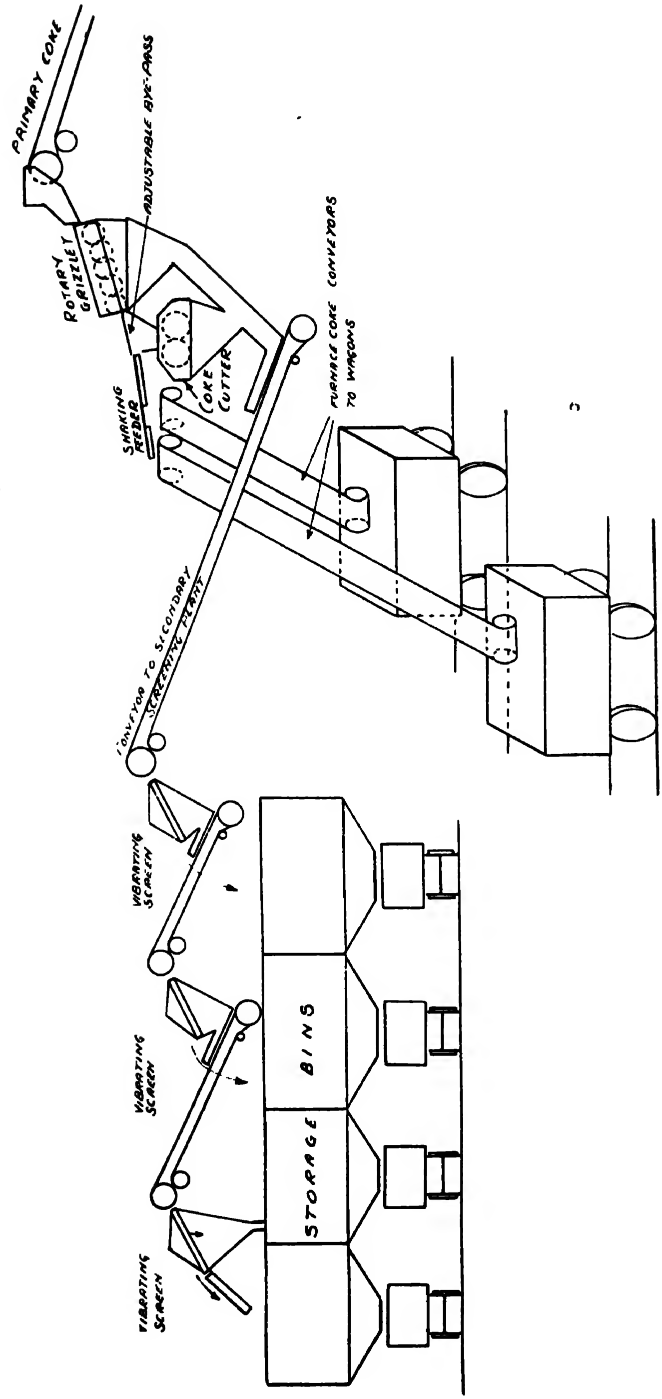


Fig. 7 Screening Plant with separate scalping and small coke station

four bunkers which are arranged over tracks, and the screened coke is drawn into wagons as required.

A coke cutter is arranged in the primary screening house in series with the grizzley, should it be desired to make a larger quantity of small coke than is ordinarily separated by the grizzley.

An arrangement of coke screening as recently installed in a modern gas works is shown by Fig. 8.

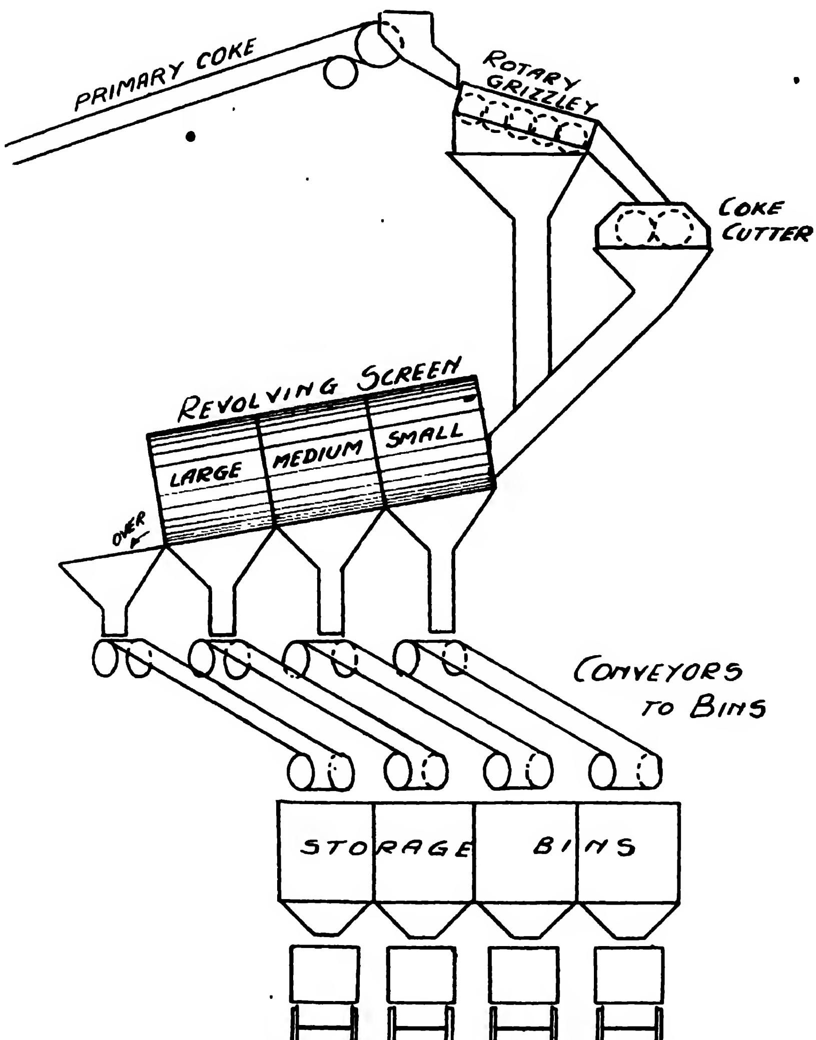


Fig. 8.
Coke Screening Plant at a gasworks.

In this case the primary coke is specially graded into a variety of sizes by a combination of rotary grizzley screen, coke-cutter and multi-product cylindrical revolving screen. The grizzley screen and coke cutter are designed to work in conjunction with each other to feed coke of a predetermined maximum size to the revolving screen, which in turn grades the coke into four distinct sizes, and delivers them on to appropriate conveyors leading to the storage bunkers, from which it is drawn to wagons as required.

ZUSAMMENFASSUNG

Koks nimmt in letzter Zeit eine solch wichtige Stellung ein, dass die Fachleute viel mehr Zeit und Aufmerksamkeit als bisher dem Problem der Herstellung der besten Maschinen zum Körnen und Sieben des Materials widmen. Zweck dieses Berichtes ist, einige neue Wege zu zeigen, die in den letzten Jahren beim Bearbeiten dieses wichtigen Problems beschritten worden sind, und die damit erzielten Erfolge bekannt zu geben.

Der Verfasser behandelt den Gegenstand unter den folgenden Überschriften.

- (*a*) Die Beschaffenheit des Kokses und Schwierigkeiten beim Fördern desselben;
- (*b*) Die Entwicklung der Siebe und die Notwendigkeit, ein Brechen des Kokses zu verhindern;
- (*c*) Beschreibung verschiedener Typen von heutzutage gebräuchlichen Kokssieben;
- (*d*) Vorschläge für Anlagen von kleinem Fassungsvermögen;
- (*e*) Beschreibung typischer Anlagen für Koksöfen und Gaswerke.

GENERAL REPORT ON SECTION G

THE CARBONISATION INDUSTRY ECONOMIC AND GENERAL CONSIDERATIONS

F. S. TOWNEND

For the purpose of this General Report the twelve papers may be grouped as follows:-

(a). Technical Aspects

i. Heat Transfer through the Walls of Coke Ovens (Germany), by K. Rummel (G2).

ii. The Use of Gross and Net Calorific Values for the purpose of Guarantee Tests (Germany), by N. F. Nissen (G3).

iii. Coke Quenching and Cooling (Great Britain), by W. Colquhoun (G.7).

iv. Coke Screening (Great Britain), by W. S. Edwards (G12).

(b) Economic Considerations

v. The Economics of Coke Manufacture in the Coking Industry (Great Britain), by M. Mackenzie (G6).

vi. The Utilisation of Coke Oven Gas by the Gas Industry (Great Britain), by T. P. Ridley (G10).

vii. The Gas Industry as a Source of Domestic and Industrial Energy (Great Britain), by F. W. Goodenough (G9).

viii. The By-Product Coke Oven as a Source of Industrial and Domestic Energy (Great Britain), by C. P. Finn and R. Ray (G5).

ix. Points of Importance for an Economical Comparison of the Value of the Heat Unit in Gaseous and Solid Fuels (Germany), by Hr. Elvers (G4).

(c) Carbonisation as National Economy

x. The Bearing of High and Low Temperature Carbonisation and Synthetic Fuel Processes on Canada's Fuel Problems (Canada), by B. F. Haanel (G1).

xi. A Brief History of the Gas Industry in Japan (Japan), by Sakura Okamoto (G11).

(*d*) *Flame and Combustion*

xii. The Fundamental Aspects of Combustion (Great Britain), by Prof. W. A. Bone, Prof. G. I. Finch and Dr. D. T. A. Townend (G8).

(*a*) *Technical Aspects*

2 Two aspects of carbonisation technique are dealt with in the first group, namely, Guarantee Tests and Coke Preparation.

3 *Guarantee Tests.* K. Rummel in the paper on "Heat Transfer through the Walls of Coke Ovens" (G2) questions the validity of stating the performance of a coke oven in the terms of production of coke per sq. metre of heated wall area per hour. This depends too much on the inherent nature of the coal and the form in which it is charged into the oven. The only criterion of the performance of a coke oven is the proportion of the total heat supplied to the oven as fuel gas which is passed through the walls. It is suggested that the efficiency of a coke oven should be recognised as:—

$$\frac{\text{"Effective Heat" (heat passed through walls)}}{\text{Total heat supplied as fuel gas.}}$$

The "effective heat" is obtained by determining the radiation and convection losses and the heat in the waste gases and subtracting the total from the amount of heat supplied as fuel gas. Two ovens giving the same proportion of "effective heat" would have the same efficiency, though the production of coke per sq. metre of heating surface per hour might be different owing to the different heat requirements of the two coals.

It is further suggested that the performance of a coke oven would be adequately represented by the following guarantees:—

1. Good oven efficiency.
2. High consumption of fuel gas per hour per cubic metre of chamber volume with a definite wall temperature.
3. Very small temperature differences in the medium plane of the coke mass.

That an official decision as to the form and extent of coke oven guarantees is required can not be doubted. Whether the proposals

in the paper under discussion are the most suitable is a matter for consideration.

4 In the same paper (G2) experimental determinations of the heat stored up and released by coke oven walls during a coking period are described. This may reach the high figure of 17,500 kilogramme calories per sq. metre per hour. It is, therefore, essential that the guarantee test should be run under such conditions of temperature control and for a sufficiently long period to render this effect of little or no influence.

5 N. F. Nissen in "The Use of Gross and Net Calorific Values for the Purpose of Guarantee Tests" (G3), gives figures which show that comparisons of efficiencies of boiler plant based on gross calorific values may be entirely different from those based on the net values. In 1925 a two-year period was officially introduced in Germany, during which both terms would be used side by side. No official decision has been reached, but in spite of the fact that the net calorific value is not capable of so precise a definition as the gross calorific value, there is an increasing tendency towards the adoption of the net value for calculating boiler efficiencies.

6 *Coke Preparation.* In the technique of coke production great interest is being taken in the preparation of the coke after it is removed from the carbonisation chamber and in the papers on "Coke Quenching and Cooling" (G7) and "Coke Screening" (G12) accounts are given of the progress which has been attained in these two branches respectively.

7 It would appear from W. Colquhoun's paper (G7) that of the methods in which water is the cooling medium the method of "remote" quenching used at most American plants and now coming into vogue in Great Britain and the Continent is most suitable for modern high-speed coking plants. It can produce a quenched coke with a constant amount of water of about 2 per cent.

8 Blast furnace operators whilst not minimising the desirability of a *dry* coke are demanding that whatever its moisture content is, it should be *constant*. It would seem that, providing this requirement is maintained, the practice of water quenching may not be entirely superseded. Nevertheless, there is a decided interest in schemes of dry cooling by which a perfectly dry coke can be obtained. The necessary plant is high in first cost and a satisfactory credit for the steam raised is essential for the installation to be an economic

proposition. W. Colquhoun (G7, page 137) gives typical conditions under which the credit for steam far outweighs the increased capital charges of the dry cooling plant. An additional advantage claimed for dry cooling is that there is a greater proportion of saleable coke.

9 W. S. Edwards (G12) points out that it is only recently that the special nature of coke has been taken into account in designing screening plant. As an example of the present unsatisfactory state, it is stated that the type of screen probably most widely used for coke screening depends on the same principle used in knocking out sand from castings, in the tube mill for grinding, and in the "Bradford" coal breaker. Special attention is called to the importance of careful consideration being given to the method of handling the coke after leaving the screens. Emphasis is laid on the disadvantages of over-rating screens and it is stated that "When installing new plant for preparing coke for the modern market, it pays to be liberal in design. The demand for a properly sized coke is growing more exacting every day and higher prices are paid without demur for a first-class product."

(b) *Economic Considerations*

10 Four of the five papers grouped under this heading deal with the coking industry and the gas industry of Great Britain. M. Mackenzie, dealing with "The Economics of Coke Manufacture in the Coking Industry" (G6), indicates that the present economic stress in Great Britain is leading to a radical rehabilitation of the iron and steel industry, on which the prosperity of the coking industry so largely depends. Whilst the modern coke oven has a high first cost, the conversion costs are approximately the same as with waste heat ovens in 1913 and are some three shillings cheaper than with waste heat ovens to-day. In labour cost alone the cost per ton of coke is reduced on modern regenerative plants from 3/9 to 1/9½. A plea is entered for a more extensive and uniform method of arriving at the costs of operation.

11 *Unification.* Reviewing the situation attention is drawn to the advantages of unification and the bulk supply of surplus coke oven gas. M. Mackenzie is of the opinion that widespread "concentration of coking units which does not form part of a larger scheme of unification and rationalisation of our principal iron and steel producing plants may defeat its own object."

This, however, will require a large capital expenditure as the present building costs for steel works are at least double that of pre-war days. It may be pointed out that this would, as in Germany, give a certain outlet for the surplus gas to the steel works and the question may be permitted whether in view of the present economic stress such concentration can *not* be afforded.

12 Unification of coking units on the grand scale is considered by M. Mackenzie to be feasible only when a user can be found for the surplus gas. The supply in bulk to the gas industry, provided adequate safeguards are given, is a question between the interested parties.

13 *Bulk Supply of Coke Oven Gas.* In natural sequence is a consideration of T. P. Ridley's paper on "The Utilisation of Coke Oven Gas by the Gas Industry" (G10). The progress both in actual sales and in the technique of gas production of the British gas industry may be observed in that during the last twelve years, the sales of gas have increased by 32 per cent. and the make per ton of coal by about 29 per cent. Naturally the gas undertakings are concerned to maintain this progress and take the standpoint that "if coke oven gas can be supplied ...... on terms and conditions which will enable gas to be sold to the public at lower prices than would otherwise be the case, there is no reason why the utilisation of such gas by the gas industry should not extend; on the contrary, it should be welcomed."

14 References are made both by M. Mackenzie (G6) and T. P. Ridley (G10) to the German scheme for bulk distribution of surplus coke oven gas, and it may be of interest to draw from them a comparison of conditions as between Germany and Great Britain. In the first place, the gas industry in Great Britain is greater than that in Germany, whilst as regards the coking industry precisely the opposite is the case. Moreover, the steel works in Germany absorb a large proportion of coke oven gas and it is only that amount, surplus to the coke ovens at German collieries, which is available for use in the German gas industry. In Great Britain only a comparatively small amount is absorbed by the steel industry. In Germany it is proposed to use the gas for the synthetic production of sulphate of ammonia, oils, and methanol and for hydrogenation of coal. The possibility of similar applications in Great Britain depends mainly on the cost of production as compared with the existing market

prices. The German scheme of long distance gas supply has in view the object of cutting out the import of foreign coal. This latter factor tends to make the cost of production of gas higher on the average than in Great Britain, and renders more feasible the supply of gas over long distances. Such a politico-economic factor as imported coal has no place in Great Britain.

15 Reverting to T. P. Ridley's paper, a detailed statement of the statutary obligations of the British gas industry is given, and it is stated that in Germany there is no special Legislation regulating the supply of gas. It would seem that the liability to these legislative penalties undoubtedly impels the requirements of adequate and stringent safeguards before the British gas industry would undertake commitment to dependence on coke oven gas.

16 In spite of this it is interesting to note that with the new contracts in 1929, the British gas industry will be absorbing approximately the same amount of coke oven gas as is at present being supplied to the German gas undertakings by coke ovens in the Ruhr.

17 From an examination of the possible amount of coke oven gas available in England, T. P. Ridley concludes that "if all the coal at present carbonised in waste heat and regenerative coke ovens were carbonised in *compound* ovens, there would not be nearly sufficient surplus gas produced to meet the total town's gas sales of Great Britain."

18 In determining the price which the gas industry can afford to pay for a coke oven gas, a list of the charges still to be borne by the gas undertaking is given by T. P. Ridley, and consideration is given to the two schemes whether the coke ovens supply a constant load, the gasworks meeting the peak demands or *vice versa*. The economic price permissible will vary with such conditions.

19 *Carbonisation as a source of Domestic and Industrial Energy.* The contribution of the carbonisation industries as sources of domestic and industrial energy are dealt with by C. P. Finn and R. Ray (G5), for the coking industry, and by F. W. Goodenough (G9) for the gas industry. The latter shows that if raw coal be carbonised and the coke be converted into electricity, then as gas and electricity there would be available about 115 therms per ton, whereas if the raw coal had been burnt directly for electrical generation, at the most, only half that amount would have been available. It is further estimated that if the 1,125,000,000 therms of gas used in

1927 for domestic and general fuel purposes had been replaced by burning raw coal, an extra 11,000,000 tons of coal would have been consumed. The contribution of the gas industry to smoke abatement need not be stressed. The gas industry is looking for freedom from the existing, and, in many respects, antiquated legislative restrictions, thereby hoping to make the use of gas still more attractive to domestic and industrial users.

(c) *Carbonisation as National Economy*

20 According to S. Okamoto, in his paper "A Brief History of the Gas Industry in Japan" (G11), after considerable fluctuations in prosperity, the Japanese gas industry is progressing, in spite of the expansion of the electrical industry. This is put down to the loosening of restrictions as to increases in the price of gas, more scientific management, and, probably not the least important, the advance in the standard of living and the increasing cost of competing fuels.

21 *Canadian Problems.* Canada, although possessing fuels of almost all kinds within her confines, stands in the position of importing a very large proportion of her fuel requirements. B. F. Haanel in "The Bearing of High and Low Temperature Carbonisation and Synthetic Fuel Processes on Canada's Fuel Problems" (G1) states Canada's fuel problem as the provision of a solid fuel for domestic heating and of liquid fuels from home sources to render herself free from dependence on foreign supplies. This demand may possibly be met by high temperature carbonisation, by low temperature carbonisation or by synthetic fuel processes. High temperature coke is acceptable in every way as a solid fuel for Canadian conditions and the gas produced is readily disposed of to communities. This method of carbonisation leaves almost untouched the problem of a supply of oil and does not avoid the importation of foreign coal.

22 The increased yield of oil in low temperature processes would permit of only a small proportion of the oil requirements being met without a large over-production of coke. It is the opinion of B. F. Haanel that the present prices of high temperature coke and crude petroleum oil which would govern the values of the two chief low temperature products are so low that low temperature processes in Canada are uneconomic unless the plants are extremely cheap, both in first cost and in operation charges.

23 There remains the possibility of utilising synthetic fuel processes. Whilst such processes may have reached some considerable degree of technical development the cost of the resulting liquid fuel is too high in comparison with the price of crude petroleum oil. The recent improvements in cracking processes, however, have made it possible to contemplate the commercial recovery of oil from the large reserves of oil shales.

(*d*) *Flame and Combustion*

24 In their paper on "The Fundamental Aspects of Combustion" (G8), Professors Bone and Finch and Dr. Townend indicate the present state of knowledge and the directions in which research is leading. From the point of view of the Conference the section dealing with the problem of "knock" in petrol-air engines is probably of most immediate interest. It is indicated that if the compression ratio could be increased from 5 : 1 to 7 : 1 the efficiency of a petrol engine should be increased by about 14 per cent. Petrol fuels unfortunately have a very marked tendency to "knock" under increased pressure ratio. Aromatic hydrocarbons and alcohol are comparatively free from this defect, and, indeed, by diluting petrol fuel with benzol the tendency may be diminished. A range of substances which suppress, in varying degrees, the tendency to "knock" are known, of which lead tetra-ethyl is the most potent. The cause of "knocking" and also the precise explanation of the behaviour of "anti-knocks" is still undecided.

DISCUSSION

WEDNESDAY, SEPTEMBER 26 (AFTERNOON)

Section G

THE CARBONISATION INDUSTRY—ECONOMIC AND GENERAL CONSIDERATIONS

Chairman: SIR DAVID MILNE WATSON, D.L. (Great Britain).

THE CHAIRMAN, in opening the proceedings, said the subject to be dealt with at this session was probably at least as wide in its scope as any other subject to be discussed at a single session. It would be agreed that the General Reporter had been most successful in the epitome which he had provided in his report of the twelve papers contributed. In effect, he had determined that the most advantageous line for discussion should be, firstly, the economics of carbonisation, and secondly, the technical considerations involved. Arising out of this second consideration was the question of the scope and determination of coke oven guarantees. A striking feature of the report was the great amount of unanimity displayed by the several contributors on various matters, as, for instance, the desirability of locating future coking plants in proximity to iron and steel works.

MR F. S. TOWNEND (General Reporter) then presented his report.

MR R. RAY (Vice-Chairman, Great Britain) dealt with one or two problems with a view to stimulating technical discussion. Referring first to methods of coke quenching and cooling, he said it was obvious, from a perusal of Mr. Colquhoun's paper, that the general decision reached was that of all the wet methods of quenching coke, that of remote quenching was most popular; and, he imagined, rightly so. Possibly delegates from Germany, where experience of coke quenching by that method was greater than in this country, would be able to enlighten us; but, from all points of view, this method would appear to be the most successful, the most efficient, and possibly the cheapest in the long run. The dry method of cooling, which was represented by the Sulzer process, was attractive, but, although it had many advantages, such as the reduction of the percentage of breeze and dust produced, there were other factors which confined its use very definitely to particular plants and particular areas. It appeared to him that in this country the question of capital cost was a very important factor, in view of the difficulty of finding a market either for the steam produced or for the electricity, which might also be produced. At all coking plants and at many gas works there was a superfluity of cheap fuel—coke breeze and coke dust—which had to be disposed of, and at present

that fuel was used to raise all the steam and electrical power required. Therefore, it was obvious that only in very special circumstances would the capital required for such a plant be forthcoming. Another point upon which Mr. Ray asked for information was that of maintenance cost. Wherever coke was handled there was very heavy wear and tear, and it had occurred to him on occasions, when looking at Sulzer plants in operation on the Continent, that the cost of maintenance and repairs must be heavy. (*Owing to indisposition, Mr. Ray then left the platform, without concluding his remarks.*)

MR. GEORGE HELPS (Great Britain) said that he wished to submit with much respect to the great conference of those interested in power production that town's gas was the ideal fuel for all purposes, even to the total exclusion of coal. He believed that town's gas was capable of being produced and sold for all purposes - with very few exceptions - at prices no greater than the coal from which it was produced - heat for heat.

In regard to coke oven gas, he did not think that coke oven people were likely to be able to sell their gas in regular quantities just as it was wanted as cheaply as gas undertakings could manufacture town's gas of adequate quality. The use of coke oven gas by authorised gas undertakings was mainly a matter of price. He was not altogether without experience of coke oven gas, because about eight or ten years ago he had arranged an option on some 7,000,000 cu. ft. per day of 500 gas at a price of 2d. or 2½d. per 1,000 cu. ft. (a halfpenny per therm), and had offered it to a particular gas undertaking in the vicinity of the coke oven plant where similar gas was costing about 1s. per 1,000 cu. ft. to produce. This particular undertaking was still thinking about it; at any rate, the gas had not been bought.

In claiming that town's gas could supersede all other fuels, he had in mind what those alternative fuels were—coal, gas, coke, coke oven gas, electricity, and oil. He honestly believed he could prove at Nuneaton that to-day gas could be produced in conjunction with oil, in such a manner that the gas could be sold at less money than coal, heat for heat, delivered to the point of consumption. When he made this claim he was not referring to a quality of 600 or 500 B.Th.U. gas per cu. ft., or to any such rich gas; which incidentally, he might mention, could not be used economically by the consumer at the pressure at which it was supplied to them. He was speaking of a gas of about 200 B.Th.U. per cu. ft., which would give far better results in many respects than the richer quality, due to the ratio between gas and air requirements, the pressure at which the rich gas was distributed, and the manner in which the consumer was forced to use it. He had been making gas in this country and abroad for nearly forty-five years, and if he were a big buyer of gas and were offered, say, a 500 and a 200 B.Th.U. gas at the same price, he would take the 200 B.Th.U. gas every time. There were many automatic advantages in the distribution of 200 B.Th.U. gas. A given initial pressure at the works with 200 B.Th.U. gas, automatically applied two-and-a-half times more power than was

applied to a 500 B.Th.U. gas for air injection purposes. He invited any who were interested in the combustion of gas to visit him at the Nuneaton Gasworks and to see what was being done there. The Nuneaton Gas Company was producing 200 therms of gas per ton of coal, or its equivalent, and from 10 to 20 gallons of oil, and no coke, although coke could be produced if desired. As to the cost of production, and selling price, of 200 B.Th.U. gas, he wished his audience to divide all gas consumers into two distinct classes, wholesale and retail; or industrial and domestic. The industrial user should be considered as a wholesale user of coal, who could buy coal at, say, £1 per ton, whereas the comparative price paid by the domestic consumer of coal was, say, £2 per ton. This was a very important matter for gas authorities to remember, because, when considering the price at which gas had to be sold to such users of coal, in order to displace it, the margin of price was much less in the case of the industrial user. In gas something like 250 therms had to be supplied to the industrial consumer for £1 to compete with coal on a heat for heat basis, which was equivalent to about 1d. per therm. There could be no question that gas produced of the quality and on the lines indicated was the only fuel which could displace coal. It was an ideal fuel, and it was the best fuel with which to produce electricity. He did not look upon electricity as a competitor just because it was an ideal source of power. He emphasised the point that the production of gas at a price to compete with coal, as carried out at Nuneaton, did not depend so much on the process by which the gas was made. The significant factor was the *quality* of gas produced which not only allowed 200 therms or so to be produced per ton of coal; but such a quality of gas to be sold in competition with coal to the advantage of the coal owner, the gas undertaking, electricity producers, and to every user of that gas.

PROF. DOUGLAS HAY (Great Britain) said he had been wondering how modern advances in fuel technology were going to help the mining industry. It might seem to be heresy even to ask the question, but he had never known the question fairly put and answered. Presumably in the long run advances in fuel technology would open up new markets and so increase the demand for coal, but the immediate effect was to contract the demand. For instance, there was the replacement of household coal by gas, coke and electricity, which meant replacing a quality of coal valued at, say, 25s. per ton at the pit head by a quality which was little more than half that value. At the same time, greater efficiency in use meant that a less quantity was being used, so that there was an immediate loss to the collieries. He was constrained to remind Mr. Ridley, the author of one of the papers contributed, who seemed to object to the collieries entering the domestic coke market, that the collieries were suffering severely from the fact that the gasworks were replacing domestic coal by gas and coke. The total tonnage of coal purchased by the gas companies was, of course, less than the tonnage which the collieries would have sold direct to the householders.

Moreover, the gas companies paid the collieries barely half the price that the latter would have obtained by the direct sale of coal, and, what was even worse, the power of barter of the large companies, both gas and electric, was such as to force the price of coal supplied to them to a level which was below the cost of production by even the most efficient collieries at the present moment. Therefore, he considered it only fair that the gas companies should assist the mining industry in disposing of surplus coke oven gas, and that they should be the last to object to the collieries entering the domestic coke market. After all, the coal industry was a basic industry in this country, and the gas companies could not live without it.

If the reconstruction of the coke oven plants in this country on modern lines were to materialise, so that there would be large central plants, each taking coal from a number of collieries, a use must be found for the surplus gas. His own company was building a large central oven plant, to carbonise 1,400 tons per day, and to take the slack from five collieries connected by aerial ropeway. The determining factor in deciding to construct this plant was that the company was able to make a contract for the supply of coke oven gas to a large town. Without that contract, the scheme would never have materialised, because the company had not only to pay off the capital charges on the new plant, but also to wipe out the remaining value of the old plants, which were still dividend producers. In general, however, Mr. Ridley's remarks were quite fair, and he welcomed them as indicating a change in the attitude of the gas companies. At the same time, he pointed out to Mr. Ridley that recent contracts did provide for a reasonable variation in the amount of surplus gas supplied from the ovens to the gas companies.

It had been suggested in the paper by Mr. M. Mackenzie, on the economics of coke manufacture in the coke oven industry, that machine mining produced more small coal than did the old hand-cutting methods. That was not his (Prof. Hay's) experience, and so fas as South Yorkshire was concerned, the contrary was the truth. The British market still demanded a large percentage of round coal, and modern methods of mining were, as a rule, directed towards reducing the amount of small coal made. This restriction tended to reduce output and increase cost, and anything that fuel technology could do to increase the demand for small coal sizes would be a help to the mining industry. This tendency was in fact observable, but he pointed out that the replacement of large and expensive fuel by small coal sizes must tend to increase the cost of the smaller sizes, and for this reason he agreed that the cost of coking smalls was likely to increase. In fact, coal prices generally, except in the case of the largest sizes, were likely to increase in the future rather than diminish. Wages in the mining industry could not be kept at the present low level; also, depths were becoming greater, seams were becoming more difficult to work, the coals were dirtier, and the miners' working day would tend to shorten. The real effect of

progress would therefore be to economise in the use of coal in different industries, but at the same time increase its value as a commodity.

MR. L. H. SENSICLE (Great Britain) said he wished to refer to the question of the supply of coke oven gas to gasworks, but before doing so a remark of the previous speaker, Prof. D. Hay, called for some comment. The latter appealed for fair play for the collieries and their coke oven plants from the gas industry by a greater readiness of the latter to take supplies of surplas oven gas. He (Mr. Sensicle) thought there was another and equally important way of regarding the question. The collieries should be anxious for the gas industry to carbonise as much coal as possible and to develop the domestic market for coke. The yield of coke was less than 70 per cent. of the coal carbonised at the gasworks, and hence if coke were substituted for coal in household consumption the output of coal at the collieries would have to expand. The development of the domestic coke market was of first importance to the coal industry, since the more the 40 million tons per annum burnt in domestic grates was substituted by coke the greater would be the increase in coal output. Of course, an expansion in coal carbonisation would lead to greater quantities of available surplus gas, but the coking industry would have to turn its attention to the numerous outlets such as were exemplified by the utilisation of the hydrogen content (amounting to over 50 per cent. of coke oven gas) in many plants on the Continent, and notably in France and Belgium, where processes were in operation for the manufacture of synthetic ammonia, the hydrogenation of oils and naphthalene; and even the hydrogenation and liquefaction of coal had been suggested.

Referring in particular to Paper G10 by Mr. Ridley, he was prompted to remark on the different outlook on the coke oven gas supply question adopted by the gas and coking industries. In the supply of town's gas manufacturing costs amounted to less than one-third of the selling price of gas, and distribution costs amounted to more than one-third. The gas industry must thus always attach a great importance to the distribution side. Expenditure on mains services, and meters, could not be curtailed or trouble would be sown for the future, while expenditure on consumers' appliances, modernisation and overhaul of those appliances, together with active sales propaganda work, had to be maintained with increasing efficiency. It was an old saying in the gas industry that profits were made in the retort house, and this was obviously true, since it was only on the manufacturing side that economies could be safely practised with a view to cheapened production. In taking over coke oven gas supply a gas undertaking had to consider among other things that it was sacrificing its controllable source of profit making; and as Mr. Ridley had pointed out, it was very necessary to look ahead and consider what future advances in gas manufacturing practice the undertaking might be omitting to obtain advantage from after going over to coke oven gas. Among the foremost of such advances was the possibility of adopting compound regenerative coke ovens

in the large gasworks. In such plant carbonisation could be maintained at a constant coal throughput as long as desired and the economies resulting from such steady working obtained. It might at present seem like heresy to a gas engineer to burn coal gas under his carbonising plant, but with such ovens decreased gas consumption could be met by doing this to the extent required, and he suggested that when the drastic economies resulting from such plant were eventually experienced, the cost of gas would not loom so large in the gas engineers' eyes. In the past the gas industry had been forced to carbonise in small uneconomic units in order effectively to meet fluctuating demands for gas, but the compound oven was going to eliminate such a necessity.

Referring to a further point in paper G10, it struck him as a most unsatisfactory state of affairs that a gas undertaking when taking a coke oven gas supply had to maintain standby plant and workmen in readiness for breakdown in the oven gas supply. The gas undertaking had its statutory obligations, but it was a waste of resources from the national point of view that such uneconomic procedure should be necessary. It seemed highly necessary that by legislation the obligation of continuity of supply and quality should be transferable to the coking concern when supplying a gas undertaking. It might be necessary to obtain some form of Government guarantee that, in the event of strikes, labour and protection and, if necessary transport of materials, would be provided by the Government in order that the town supply of gas should not suffer.

MR. THOMAS HARDIE (Great Britain), dealing with the economic considerations affecting the carbonising industry, said that the gas engineer had for some years had every reason to be satisfied with the progress of his industry. The consumption of gas had continued to increase steadily, cost of production had been reduced, the efficiency of his processes had been increased, maintenance of the plant to the most modern standard had been possible and the selling price of gas had shown a steady and regular reduction, whilst the demand for gas coke for domestic purposes had also exhibited a satisfactory and steady increase. With the internal economics of the metallurgical coke industry he (Mr. Hardie) was not so familiar, but all was apparently not too well, and longing eyes appeared to be turned to the markets of the sister industry to meet the shortages and disappointments of its own. Co-operation between two industries, so closely allied in their raw material and in their products, would appear desirable. While it was very many years since the first surplus gas from coke ovens was purchased by a statutory gas undertaking in this country, the markets for the main products of the two industries had been so different in the past that, except in the case of the less important by-products, no approach to joint marketing had been made, nor was it necessary. Possibly the fact that the coke oven owners were also largely the purveyors of coal to the gas industry made them in the past consider it undesirable to disturb what was a lucrative market for their coal; and the two industries had continued to work in their own particular fields, the

collieries being satisfied with the profits upon the coal they sold to the gasworks and the profits from the coal they treated in their own ovens.

Conditions had now altered. Depression in the iron and steel trades had resulted in a falling off of the demand for metallurgical coke. He gathered, from Mr. Mackenzie's remarks, that in his opinion, even should the steel trade recover, such improvements were being made in its productive methods, effecting an economy in coke, that the future demand for metallurgical coke would with difficulty attain the dimensions of past years.

The question which faced coal owners, then, was how best to restore the profits from their coke oven activities. It was only natural, when proposals for the domestic utilisation of surplus oven gas on the Continent and elsewhere were the subject of much discussion, that similar ideas should be brought forward in this country, though it was well that the difference in the conditions of the industries of the two countries should receive careful consideration.

The gas industry was quite prepared to consider such proposals sympathetically, but they did wish to be satisfied, quite apart from the question of price, that their consumers would not suffer either in the security or in the efficiency of their supply, and that the national interests of the community would in no way be adversely affected. The raw material treated by the two industries was almost identical, and there was little difference in the market prices of their coal. The resulting products were much the same, though the value of gas coke had for some years exceeded that of oven coke. The principal difference in the financial results of the processes, however, lay in the fact that the gas industry produced for sale about 8,000 cu. ft. of gas more to the ton of coal, and from 3 to 3½ cwt. less of coke than the coke ovens. The undoubted advantage to the gas industry of this greater production of gas and lesser production of coke was very definitely confirmed by the present endeavours of the coke oven owners to convert their plants to obtain more nearly the results of the gas plant. From a broad view it was clear that gas plant with equal priced coals would produce gas more cheaply, and fancy comparisons with selling prices of domestic gas, or even with prices of gas into holder, unless proper allowances were made for the varying load the gas manufacturer had to meet, for the increased maintenance due to the necessity of replacing out-of-date plant, for the condition of wages, welfare of employees, and other advantages gained by many years of arduous development, were unreliable.

The installation of coke ovens had been considered by all the largest gas undertakings, but only in one case were ovens installed, and, though that was many years ago, it had not been repeated. (In the current issue of the *Gas Journal* it was stated that those ovens were for sale.) Even when operating on a base load it was difficult to see wherein the coke oven was going to obtain the extra 3½d. to 4½d. per 1,000 cu. ft. with which its surplus gas must be charged in order to meet those basic items which Mr. Ridley had

shown to be so essential for a gas undertaking to take into account when purchasing oven gas.

It would appear, then, that there was a catch somewhere in the low price at which coke oven plant was reputed to be able to supply gas; and it was satisfactory to have the assurance of the President of the Board of Trade that the enquiry recommended by the National Fuel and Power Committee into the possible supply of towns from coke oven installations would be made, when the mystery would no doubt be explained. The similar schemes which were now commencing in Germany were often quoted without mention of the fact that by far the greatest portion of the gas was, or would be, absorbed by steel works. It was stated in a paper in another section of the Conference (paper H10, by Mr. H. Blauvelt) that in America 62 per cent. of all the surplus coke-oven gas was used in steel works. It would be interesting to know what was the percentage in this country. Mr. C. P. Finn and Mr. Ray, in their paper, considered the ideal condition to be the erection of coke ovens as a part of iron and steel works, and this opinion was confirmed in other papers presented to the Conference, notably by Dr. Bansen, of Germany (paper K7) and M. Berthelot, of France (paper W2). Wherever this co-ordination had taken place, success appeared to have attended coke oven operations. Mr. Mackenzie had gone still further, and had suggested the necessity for larger steel works as well as concentrated coke oven plants. There was one combine working in the United States which carbonised 32,000 tons of coal per day, and which absorbed the whole of its production of coke and gas in the metallurgical processes. Did not this indicate to the coke oven industry a way to success? It suggested closing down their own inefficient plant, and building a large combined one which would permit them to compete successfully in their proper markets. It appeared very desirable to give the most serious consideration to this combination of coke ovens and steel works before extensive reconstructions of oven plant situated at collieries were undertaken on the strength of the hope of a market for the gas produced, and of a domestic market for coke. There would be no increase in these markets because they were supplied from coke oven sources instead of from the gas works.

The efforts of the gas industry to improve the suitability of coke by grading, and in educating the public to its advantages, had led to an increase in the use of coke in the homes of the people. Although there was a very large quantity of coal used for domestic purposes which could still be displaced by coke, yet the rate of progress was by no means so rapid that it could not be met by the unaided production of the gas industry. To prevent slumping in its markets the gas industry had always found it necessary to regulate the output of coke for sale by the manufacture of water gas; nearly 1½ million tons of coke were so absorbed in 1926, and in 1927 the quantity exceeded one million tons. If the whole supply had been met by plant producing only coal gas the market last year would have had to absorb 5 million tons more coke. Large

quantities of gas coke were exported, the quantity last year being approximately 1 million tons. The entry of oven coke manufacture into the domestic markets for coke would not result in any additional demand, but would simply replace a demand which was being met satisfactorily by gas undertakings, and would in addition force down the price to an unremunerative figure for all parties. No benefit would be obtained by the coal industry in general; one colliery might benefit, but at the expense of another. The gas industry had the record of being highly efficient, and its charges in this country compared favourably with those in either America or Germany; and while special cases undoubtedly existed in certain parts of the country favourable at present to the supply of gas to gasworks from coke oven plants, it was impossible, in his opinion, that the work of gas manufacture and domestic coke production should be transferred to any extent to the national advantage on a scale which would provide a solution of the difficulties of the furnace coke manufacturer or of the coal industry.

LIEUT.-COL. W. M. CARR (Great Britain) said that many of the delegates from other countries might think that there was a great difference of opinion between the town's gas suppliers and the colliery people in this country. He did not think, however, that this difference really existed. The town's gas suppliers were anxious, desperately anxious, to give a supply of gas at a lower rate, and to diminish the smoke nuisance, in collaboration with the producers of coal; and whether the coal was dealt with at the gasworks, or whether the gas undertakers received the surplus gas from the coke oven plants—and he did not believe the amount of surplus coke oven gas going to waste in this country to-day was considerable—the amount of coal carbonised was the same, provided the efficiency in both cases was the same. The question as to whether or not the production should be transferred from the town's gasworks to the pit head was one deserving of very careful consideration. As had been stated, it would appear desirable from the point of view of the coke oven owners that the coke ovens should be situated at the steel works, and undoubtedly in those circumstances the cost of production, as compared with the cost of production in gasworks, would permit them to afford supplies to town's gas undertakings in the particular area at a price lower than that at which it could be made at the gasworks. There was no doubt that the load factor of a particular town's supply had a good deal to do with the question of whether coke oven gas could be made available economically to gasworks at considerable distances from the coke ovens. If there were a good load factor and a considerable industrial load, and the demand was spread fairly evenly over the twenty-four hours, then the mains for the long-distance transmission and the storage facilities at the point of user would be small, and the capital cost would be low, so that the supply of coke oven gas would possibly prove economical. There were many cases, however, in which the economic conditions and the situation in respect of load factor would not permit the supply of coke oven gas, however

much the gas undertakers might desire to obtain it. Another point of great importance was that, inasmuch as town's gas was sold on the thermal basis, it must have a constant calorific value, and many gas undertakers were pivoting their thoughts upon the problem of keeping the calorific value constant, or keeping the variation down to about 0·5 per cent. He had heard that in some cases of coke oven gas supply variations up to 10 per cent. had had to be met. That was a point which must be considered very carefully when an undertaking was to rely solely on a supply of coke oven gas for its requirements. Referring to the coke used in the coke ovens, he said that practically the whole of it consisted of the smalls which were screened out of the coal supplied mainly to the gas undertakings, and therefore, if we were to rely solely upon coke oven gas for the supply of a large area, the average price of the coal-- not only the price of the smalls, but the pit price of the coal which would presumably have to be broken down before it went to the ovens with the smalls- would have to be taken into consideration. That was a matter of importance when arriving at the price of coke oven gas for a contract covering a period of years.

MR. N. F. NISSEN (Germany), referring to the paper which he had presented (G3), called attention to one of the principal reasons why users, as well as boiler makers in Germany, tended to use the net calorific value for efficiency: namely, the influence of the water when the water content of the coal was large. Up to now not much attention had been given to this factor in most countries, because the use of lignite was small. In Germany, however, it constituted in value about 25 per cent. of the coal used for industrial purposes. In most cases it was not possible to procure a fuel with exactly the same moisture as that fixed in the guarantees. If, for example, an efficiency of 73 per cent., based on the gross heating value had been warranted, and the testing fuel contained 58 per cent. moisture instead of 50 per cent., as laid down in the guarantees (in reality even greater variations were possible), the result would show a deficit of four units compared with the efficiency which would have been obtained with a fuel as fixed in the guarantees. If the efficiency would just have been sufficient with the fuel designated in the guarantees the test would actually show an efficiency of 69 per cent. only, owing to the higher water content of the testing fuel. The permissible deviation of 5 per cent. as accepted in Germany in this particular case 3·65 units of efficiency, would have been exceeded. Besides the real purpose of the permissible deviation (to balance the errors in measurement), had not been served. The acceptance of the plant might be refused in spite of the fact that the plant was actually working well enough to satisfy the guarantees given.

MAJOR C. F. ELLWOOD (Great Britain), referring to the costs of handling coke at the colliery with which was connected, by means of the Greensmith "Quencher Conveyor," as given in Mr. Colquhoun's paper (G7), pointed out that those costs were higher than they would have been if the throughput of the plant were greater.

There was only one man on the machine, and his entire wages were charged to coke handling, although his duties included lowering wagons and assisting in opening oven doors. Provided the plant were equipped with a cooling wharf on which the coke could be discharged, so releasing the machine, an oven could be discharged over the machine every five minutes by the same man quite comfortably. The quantity of water used for quenching coke was an important consideration, and with the plant in question it was found that only 70 gallons were required per ton of coke. This was a great saving in the cost of pumping and no water came in contact with the ovens. No system would quench and cool coke in less than thirty-five minutes sufficiently to enable it to be loaded into wagons unless the coke were absolutely soused with water, but with this system, working in conjunction with a cooling wharf large enough to hold three or four ovens, the moisture in coke could easily be kept down to what might be called a bone-dry condition. The cost would be still further reduced if the charge per oven was 9 tons instead of 6 tons. Finally, he said that the capital cost of the Greensmith machine was only about half that of the remote quencher.

MR. J. E. LISTER COOPER (Great Britain) pointed out that one of the results of the taking of a supply of coke oven gas by a gas undertaking was that the rating assessment of the gas undertaking would be increased. He had knowledge of cases in which the rating assessment on gas undertakings which had commenced to take supplies of coke oven gas had been more than doubled, by reason of the fact that they were no longer entitled to certain allowances with respect to tenants' capital. One small undertaking, with an output of 74 million cu. ft. per annum, had a rating assessment of under £1,200, but when it began to take a supply of coke oven gas, the assessment was increased to £4,500. On appeal, this was reduced to £1,950. Seeing that the amount paid in rates by a gas undertaking was generally about 2½d. or 3d. per 1,000 cu. ft., an increase of a further 3d. per 1,000 cu. ft. was an important consideration.

MR. JOHN ROBERTS (Great Britain) said he was sorry to note that there was antagonism between sister industries. The coke oven industry was being accused of encroaching upon the markets of the gas industry, but, rather than that these two industries should attack each other, he would prefer to see them combining to attack the common enemy—by which he meant the domestic grate. In this country, 35 million tons of raw coal was being burned annually in domestic grates. The gas industry ought to be concentrating upon the creation of a new market for coke to displace raw coal. He believed the coke oven and the gas industries could make a fuel which would be much superior to any domestic coal used in the open grate to-day, a fuel which would be of universal application so far as the domestic grates were concerned.

DR. E. W. SMITH (Joint Technical Secretary), commenting on Mr. Roberts' remarks, said he had read the papers submitted to the

Section and had followed the discussion closely, but could see no sign of an attack by one industry upon the other. He understood there was to be a committee of some kind appointed by the industries concerned to go into this matter. Quite likely it would be found that in some cases coke oven gas could be sold at a price low enough to attract a gas company whose prices for town's gas happened to be high enough to justify purchasing the coke oven gas. There were other considerations, of course. He urged that those who had attended the meeting of the Section should not leave in the belief that there was an attack of one industry upon the other. There was quite a proper safety-first attitude on the part of the gas industry, and quite a proper acquisitive attitude on the part of the coke oven industry, and he suggested that the matter be left there for the present.

MR. H. VAN HETTINGA TROMP (Dutch East Indies) drew attention to the possibilities of making good coke from coals which, by reason of their chemical constitution were non-caking, and he mentioned a case in which this had been achieved. The caking power of coal, he said, depended on the amount and character of its bitumen content. Fischer, of Germany, had even distinguished two different kinds of bitumen, the one soluble and the other insoluble in petrol-ether; the one giving the swelling power and the other the caking power in the coke. (*Brennstoff Chemie*, 1925.) The amount of really good caking coal available was diminishing, not only in this country, but practically all over the world. In the Dutch East Indies, where the tertiary coal was non-caking, the problem of making a good coke for blast furnace purposes from non-caking coal had become a very important one some years ago, when the possibilities of establishing an iron and steel industry on the south-east of the island of Borneo were earnestly discussed. Iron ore and coal were plentiful, but comprehensive tests had demonstrated distinctly that it was quite impossible to make a compact coke in the ordinary coke ovens from this kind of eocene coal, owing to its high volatile content (45 per cent.). The coke obtained was all fine. The tests were repeated in different plants by well-known experts in Germany and Belgium, and ultimately it was shown that a good compact coke could be made in *vertical* retorts of gas-works from the lump coal. The opinion of the experts was, that this coke could be used successfully in blast furnaces having a daily output of 100 tons. Coke-making in Borneo could not be carried out, however, because there were no consumers for the slack coal (amounting to more than 50 per cent.) remaining after separating the lumps for the coke ovens. He suggested, however, that in industries, which could use the slack as well as the lump coal, it would be of the greatest interest to try this method of coke making from the lumps of non-caking coal.

THE CHAIRMAN, in closing the discussion, endorsed Dr. Smith's view with regard to the position as between the coke oven industry and the gas industry. So far from there being any feeling of animosity between the two, he said, there was a desire on the part of

the coke oven industry to sell its gas to the gas industry; and there was the natural "shyness" on the part of the gas industry, until it knew what its position was, about accepting the suggestions made to it without a good deal of enquiry. That was only what one would expect and was bound to find in any well-conducted industry. Some six months ago the two industries, of their own volition, had decided to appoint a joint committee to discuss the questions arising between them. That certainly did not look like animosity, but rather a desire to understand each other's position, and if possible to help each other in the solution of the problems which had presented themselves. Referring to the suggestion of the National Fuel and Power Committee that there should be an investigation into the whole of this question in an area lying in the centre of England, Sir David said that, as he was a signatory to that recommendation, it was well that he should remove any misunderstanding that might arise,. by stating that in signing the recommendation he was merely approving the suggestion that an investigation should be held into all the facts. It must not be assumed that he approved of the proposals. The investigation was most desirable because we did not know at present how much coke oven gas was really surplus to-day, how much would be surplus in the future, when the needs of the iron and steel industry were met, or whether the distribution of any surplus coke oven gas that might exist, by the gas undertakings, would in fact make the public gas supply cheaper or dearer. Finally, Sir David again emphasised that there was no animosity between the coke oven and the gas industries, and that everything was to be gained by considering how far they could co-operate.

The proceedings then terminated.

SECTION H

COMPOSITION, CLASSIFICATION, PREPARATION, STORAGE AND HANDLING OF GASEOUS FUELS AND OF THE PRODUCTS OF THE CARBONISATION INDUSTRY

THE NUMBERS ARE THOSE GIVEN TO EACH PAPER FOR USE AT THE FUEL CONFERENCE

DIE EINHEITLICHE BENENNUNG TECHNISCHER GASE

(A SYSTEMATIC CLASSIFICATION OF TECHNICAL GASES)

GESELLSCHAFT FÜR WÄRMEWIRTSCHAFT, WIEN

*Paper No. H*1

CONTENTS

STANDARDISED METHOD OF DESCRIBING AND GROUPING TECHNICAL GASES

ENGLISH VERSION (ABRIDGED)

Schon seit langer Zeit wurde in der Technik die verschiedenartige Benennung und Gruppierung der technischen Gase als fühlbarer Mangel empfunden. Die Gesellschaft für Wärmewirtschaft Wien hat im Verlaufe ihrer Arbeiten auf dem Gebiete der gasförmigen Brennstoffe daher schon vor längerer Zeit auf Anregung von Hofrat Professor Dr. Strache († Technische Hochschule Wien) in Oesterreich den Vorschlag gemacht, einheitliche Benennungen für technische Gase, vor allem Heiz-, Leucht- und Kraftgase, festzusetzen. Dieser Vorschlag fand grosses Interesse bei deutschen Fachkreisen, so dass schon gelegentlich der Jahresversammlung 1924 des Vereines deutscher Gas- und Wasserfachmänner in Nürnberg, auf Grund eines Entwurfes der Gesellschaft für Wärmewirtschaft einheitliche Bezeichnungen erstmalig vereinbart werden konnten. Dieser Nürnberger Beschluss fand wohl in Interessentenkreisen weitgehende Zustimmung, doch wurden auch Gegenstimmen laut, so dass sich der Normenausschuss der deutschen Industrie veranlasst sah, den Nürnberger Entwurf sowie einen Gegenentwurf der Brennkrafttechnischen Gesellschaft (Berlin) zur allgemeinen Kritik zu veröffentlichen. Dieser Schritt des deutschen Normenausschusses führte zu dem Ergebnis, dass in Oesterreich und Deutschland ein Normenentwurf auf Grund des Nürnberger Entwurfes, welcher die meiste Zustimmung gefunden hatte, aufgestellt wurde.

Dieser Entwurf erfuhr durch Vorschläge aus den zuständigen Fachkreisen noch einige nicht sehr wesentliche Abänderungen und Ergänzungen und erscheint nunmehr in Deutschland und Oesterreich gutgeheissen.

Im Zuge der Bearbeitung dieses Gegenstandes wurde auch angeregt, die Festlegung der Systematik der brennbaren technischen Gase der internationalen Fachwelt zur Diskussion zu stellen. Die Gesellschaft für Wärmewirtschaft glaubt, durch Hinweis auf die genannten von Oesterreich ausgegangenen Arbeiten bei der Fuel Conference 1928 eine Entwicklung in dieser Richtung zu fördern.

BRENNBARE TECHNISCHE GASE
BENENNUNG

Gruppe.	Gewinnung.	Art.	Unterarten	Verbrennungswärme (früher oberer Heizwert) kcal/m³ bei 0°C und 760 mm QS.	Bemerkungen
Gas aus festen Brennstoffen	Durch Entgasung	Schwelgase	Holz-, Torf-, Braunkohlen-, Steinkohlen- u Schiefer-Schwelgas	3 000 bis 8 000 und höher	Schwelgase, früher auch Urgase genannt, entstehen bei Temperaturen unterhalb Rotglut (meist bei 450° bis 550°)
		Destillationsgase	Holzgas, Torfgas, Braunkohlengas, Steinkohlengas (Kokereigas)	4 000 bis 6 000	Destillationsgase entstehen bei Temperaturen oberhalb Rotglut
	Durch Vergasung	Schwachgase	Gichtgas	700 bis 900	Gichtgas entweicht d. Gicht d. Hochofens u. enthält ausser Stickstoff vornehmlich Kohlenoxyd u. Kohlensäure
			Generatorgas	800 bis 1 800	Generatorgas entsteht bei Vergasung eines Brennstoffes unter Zufuhr von Luft oder Luft u. Dampf. Frühere Sonderbezeichnungen: Luftgas, Siemensgas, Mischgas, Dowsongas (Halbwassergas)
			Mondgas	800 bis 1 500	Mondgas entsteht bei Vergasung eines Brennstoffes unter reichlicher Zufuhr von überhitztem Wasserdampf u. niedriger Reaktionstemperatur zwecks erhöhter Ammoniakgewinnung
		Wassergase	Wassergas	2 500 bis 2 900	Wassergas od. blaues Wassergas, früher auch Koksgas genannt, entsteht durch Einblasen von Dampf in eine hocherhitzte Brennstoffschicht (Koks oder gasarme Brennstoffe). Sonderart: mit Oelgas oder Benzoldämpfen angereichertes Wassergas, karburiertes Wassergas
			Kohlen-Wassergas	3 200 bis 3 500	Kohlen-Wassergas entsteht im Wassergasbetrieb als Gemisch von Wassergas mit Schwelgas. Sonderbezeichnung: Doppelgas

BRENNBARE TECHNISCHE GASE
BENENNUNG

Gruppe.	Gewinnung	Art	Unterarten.	Verbrennungswarme fruher oberer Heizwert) kcal/m³ bei 0°C und 760 mm QS.	Bemerkungen.
Gase aus flussigen Brennstoffen	Durch Verdampfung	Kaltluftgase	Benzinluftgas, Benzolluftgas	2 000 bis 3 000	Kaltluftgase entstehen durch Beladen von Luft mit Dampfen flussiger Brennstoffe bei mässigen Temperaturen Sonderbezeichnungen: Aerogengas, Benoidgas, Pentairgas.
	Durch Zersetzung bei höheren Temperaturen	Spaltgase	Oelgas, Fettgas, Blasengas	4 000 bis 17 000	Spaltgase entstehen durch Ueberhitzung von Oel- oder Urteerdampfen unter Luftabschluss. Sonderbezeichnungen: •Pintschgas, Blaugas, Flussiggas (die beiden Letzteren sind bestimmte durch Verdichtung verflussigbare Anteile v. Oelgasen).
Naturgase	Entstehen ohne technische Einwirkung	Methangase	Erdgas, Methangas, Faulschlammgas	8 000 bis 9 000	Erdgas kommt naturlich vor, Methangas wird jedoch auch aus Kokereigas gewonnen
Gase aus Nichtbrennstoffen		Karbidgase	Azethylen	12 000 bis 13 000	Karbidgase werden aus Karbiden und Wasser erzeugt
		Wasserstoff		3 000 bis 3 100	Wasserstoff wird durch Elektrolyse erzeugt oder durch Zersetzen von Kalziumhydrid (CaH_2) mit Wasser oder von Wasserdampf mit Metallen (Er wird jedoch technisch auch aus Wassergas oder anderen gasförmigen Brennstoffen gewonnen).

ALLGEMEINE BETRIEBSBEZEICHNUNGEN

Art	Unterart	Bemerkungen
Stadtgas	Steinkohlengas (Kokereigas), Braunkohlenschwelgas, Wassergas, Doppelgas oder Gemische und Umwandlungsprodukte aus diesen Gasen	Stadtgas (bisher vielfach Leuchtgas genannt) dient zur Versorgung von Gemeinden und Industrien aus einem der städtischen Gasversorgung dienenden Rohrnetz
Rohgas		Rohgas ist ungereinigtes Gas (fruher auch als Produktionsgas bezeichnet)
Reingas		Reingas (bei Generatorgas auch Kaltgas genannt) ist gereinigtes und von Nebenprodukten befreites, zu diesem Zwecke meist abgekuhltes Gas
Sauggas		Sauggas ist Generatorgas, das die Gasmaschine entsprechend ihrem Bedarf vom Generator ansaugt

A SYSTEMATIC CLASSIFICATION OF TECHNICAL GASES

(English Version—Abridged)

Some time ago the "Society for Heat Economy," Vienna, advanced proposals for a standardised method of describing and grouping technical gases. These suggestions, which were recommended by Dr. Strache, evoked

TECHNICAL COMBUSTIBLE GASES.
CLASSIFICATION.

Group.	Process.	General nature of the gas.	Particular nature of the gas.	Calorific Value Kcal/M³ at 0°C+760 mm. Hg	Observations.
Gases from solid combustible substances	By carbonisation	Low temperature distillation gases	Wood, peat, brown coal, hard coal and shale, low temperature distillation gas	3,000 to 8,000 and above	Low temperature distillation gases formerly known as "Urgase" produced at temperatures below red heat (mostly 450°C to 550°C.)
		Carbonisation gases	Wood gas, peat gas, brown coal gas hard coal gas (coke oven gas)	4,000 to 6,000	Distillation gases produced at temperatures above red heat.
	By complete gasificat on	Lean gases (low grade gases)	Blast furnace gas	700 to 900	Blast furnace gas passes out of the throat of the blast furnace and contains principally nitrogen, carbon monoxide and carbon dioxide.
			Producer gas	800 to 1,800	Producer gas is produced by the complete gasification of a fuel with air, or air and steam. Otherwise known as air gas, Siemens gas, mixed gas, Dowson gas (semi-water gas).
			Mond gas	800 to 1,500	Mond gas is produced by complete gasification with an ample quantity of superheated steam and lower reaction temperatures to enable a greater ammonia recovery
		Water gases	Water gas	2,500 to 2,900	Water gas or blue water gas, formerly also known as "Koksgas" is produced by blowing steam through a bed of fuel at a high temperature (coke or other gas free fuel). When enriched with oil or benzol vapour becomes caburetted water gas.
			Tully gas	3,200 to 3,500	Tully gas is produced in water gas practice as a mixture of water gas with low temperature distillation gas Otherwise known as "Doppelgas"
Gases from liquid combustible substances	By vapourisation	Cold air gases	Petrol air gas Benzol air gas	2,000 to 3,000	Cold air gases are produced by the saturation of air with the vapours of liquid fuels at ordinary temperatures. Otherwise known as "Aerogan gas," "Benoid gas," "Pentair gas."
	By decomposition at higher temperatures	Gases from cracking processes	Oil gas, Rich gas, "Blasengas"	4,000 to 17,000	These gases are produced by the superheating of oil or low temperature tar vapour in the absence of air, otherwise known as Pintsch gas, blue gas, "Flussiggas" (Both the latter are produced by the liquefaction processes).
Natural Gases	Produced without technical operations	Methane gases	Fire-damp Methane. Putrefactive gases	8,000 to 9,000	Fire-damp occurs naturally while methane can also be obtained from coke oven gas.

TECHNICAL COMBUSTIBLE GASES CLASSIFICATION.

Group.	Process.	General nature of the gas.	Particular nature of the gas.	Calorific value Kcal/M^3 at $0°C + 760$ mm. Hg.	Observations.
Gases from non-combustible materials		Gases from carbide	Acetylene	12,000 to 13,000	These gases are produced by the action of water on carbide.
		Hydrogen		3,000 to 3,100	Hydrogen is produced by electrolysis or the decomposition of hydrolith (calcium hydride CaH_2) with water, or water vapour with metals. (It is also obtained technically from water gas or other gaseous fuels.)

GENERAL INDUSTRIAL TERMS.

Section	Sub section.	Observations.
Town's gas	Coal gas (coke oven gas), brown coal, low temperature distillation gas Tully gas, water gas or mixtures and derivatives of these gases.	Town's gas—formerly often known as lighting gas—supplies domestic and industrial requirements through service supply pipes.
Raw gas		Raw gas is unpurified gas (formerly also known as crude gas).
Purified gas		Purified gas—known as cold gas in the case of producer gas—is cleaned and stripped from by-products. For this reason mostly cooled gas.
Suction gas		Suction gas is producer gas produced according to the requirements of the gas engine.

considerable attention among German technical circles and finally led to the acceptance of a plan based on the proposals of the "Society for Heat Economy" at the Annual Conference (1924) of the "Union of German Gas and Water Engineering."

The criticism of the original scheme necessitated the publication of both these and the counter proposals of the "Society for Fuel Economics" (Berlin), and general discussion was invited on the subject.

The Nuremberg plan was preferred by the majority and was eventually adopted with minor alterations by both the Austrian and German Standard Committees. It is felt that standardisation on lines similar to those originated in Austria would be of international interest, and a move in this direction is looked for at the Fuel Conference, 1928.

DIE ANWENDUNG DES EXPLOSIONSPRINZIPES ZUR GASHEIZWERTBESTIMMUNG

(THE APPLICATION OF THE EXPLOSION PRINCIPLE TO EVALUATION OF THE HEATING VALUE OF GASES)

AUSTRIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

DR. H. LÖFFLER

Paper No. 112

CONTENTS

HISTORICAL—A NEW "EXPLOSION" GAS-CALORIMETER—BIBLIOGRAPHY RÉSUMÉ

ENTWICKLUNG

Zum ersten Male verwendete zur Bestimmung der Heizkraft und des Leuchtwertes von Gasen Prof. Teclu 1909 eine von ihm konstruierte und beschriebene Apparatur in welcher durch natürliche Diffusion von Luft in Gas in einem Raum konstanten Volumens sich die Explosionsgrenze selbsttätig einstellt und durch Verpuffung der dabei entstehende Druck mittels einer mechanischen Vorrichtung abgelesen wird. Später ersann Strache 1910 ein Instrument welches gestattete, ein bestimmtes Volumen Gas, dessen Umrechnung auf Normalbedingungen durch die Art der Vergleichsablesung erspart blieb, in einem geschlossenen Raum zu verpuffen und die bei der Verpuffung frei werdende Wärmemenge auf manometrischem Wege durch die erfolgte Ausdehnung eines Luftmantels zu messen. Die Apparate dieser Art, mehrfach beschrieben, kamen nur wenig in praktische Anwendung da sie ganz aus Glas, daher leicht zerbrechlich und der Grösse wegen unhandlich waren. Bald darauf wurde an Stelle des Luftmantels und der Uebertragung der Wärme an denselben, inmitten des Explosionsraumes die Kugel eines Thermometers eingesetzt und der Heizwert, resp. die erzeugte Wärmemenge aus dem Temperaturanstieg dieses Thermometers berechnet. Das Gas wurde dabei durch freies Durchstreichen durch

eine Pipette selbsttätig abgemessen und durch ein verstellbares Wasserniveau in den Explosionsraum eingesaugt nd mit Luft gemischt.

Apparate dieser Bauart wurden "Kaloriskop" genannt und hatten infolge verschiedener Konstruktionsfehler eine Genauigkeitsgrenze von ca. 3 %. In der Folge, besonders in den Nachkriegsjahren wurde das zuerst beschriebene Prinzip beim Bau des Unionkalorimeters verwendet, wobei anstelle des Luftmantels eine Flüssigkeitsschichte, anstelle der Vergleichsmessung mit einem Luftvolumen einmal einstellbarer Grössenordnung, die Vergleichsmessung mit Knallgas, welches vor jeder Bestimmungsreihe im Apparat durch einen Akkumulator erzeugt wird, getreten ist. Unter Berücksichtigung der im folgenden Abschnitt gegebenen theoretischen Grundlagen der Explosionskalorimetrie wurde das ehemalige Kaloriskop in einen Apparat umgewandelt, dessen Genauigkeit bei richtiger Arbeitsweise $\frac{1}{3}$% beträgt, und dessen Beschreibung im Abschnitt 3 erscheint.

Theoretische Grundlagen

Während bei einer grossen Zahl von Apparaten zur Bestimmung des Heizwertes von Gasen ein kontinuierlich fliessender Gasstrom in einem geeigneten Brenner zur Verbrennung gebracht wird und seine Wärme an einen ebenfalls fliessenden Wasserstrom oder auch Luftstrom abgibt und also ausser der Temperatursteigerung des letzteren auch die durchfliessenden Gas- resp. Wassermengen genau abgemessen werden müssen, verwendet die Explosionskalorimetrie eine verhältnismässig kleine Gasmenge, die sie mit Luft gemischt in einem abgeschlossenen Raum zur Entzündung bringt. Die Vorteile die aus der Anwendung derartiger Apparate sich ergeben, liegen vor allem in der vielseitigen Anwendungsmöglichkeit sowie in der jederzeitigen Betriebsbereitschaft, da die umständliche Anbringung von Wasserzu- und -ableitungen entfällt.

Während das seinerzeitige Strache-Kalorimeter und auch die ursprüngliche Ausführungsform des Kaloriskop keine Abstufung in der Mischung von Gas mit Luft erlaubte, anderseits umfangreiche Untersuchungen ergaben, dass die zwischen den beiden Explosionsgrenzen liegenden Mischungsverhältnisse weiter eingeengt werden, durch die Grenzen der vollkommenen Verbrennung, musste ein für alle Gase verwendbares Kalorimeter eben jedes Mischungsverhältnis herzustellen erlauben. Man soll somit in Kenntnis des ungefähren

Luftbedarfes eines zu untersuchenden Gases sein, oder sich diese Kenntnis durch reihenweise Anwendung verschieden grosser Pipetten verschaffen. Diejenige welche den höchsten Wert liefert, ist dann die zutreffende. Die allgemeine Anschauung, dass der Luftbedarf aus der Grössenordnung der Kalorien hervorgeht, z.B. ein 4000 Cal-Gas 4-fachen Luftbedarf besitzt, kann hiebei irreführend sein.

Die Form des Explosionsraumes spielt eine grosse Rolle, besonders dann, wenn das Gasluftmischungsverhältnis sich der Grenze der vollkommenen Verbrennung nähert. Die grösste Sicherheit in Bezug auf Gewährleistung der vollkommenen Verbrennung gibt der kugelförmige Explosionsraum in dessen Mittelpunkt die Zündung eingeleitet wird. Alle anderen Anordnungen geben nur bedingt richtige Werte, nur dann wenn die Mischungsverhältnisse besonders günstig liegen. Man kann diese Vorgänge im dunklen Raum gut verfolgen und konstatieren, wie z.B. im lang gestreckten Explosionsraum die Flamme langsam nach abwärts wandert und oft das untere Ende des Behälters nicht mehr erreicht. Eine gleichmässige Druckfortpflanzung gewährleistet eine gleichmässige Beschleunigung der Zündgeschwindigkeit und diese letzten Endes eine vollkommene Verbrennung bis nahe zu den Explosionsgrenzen.

Während der Vorgang der Wärmeübertragung zur Messung des Heizwertes bei Kalorimeter mit fliessendem wärmeaufnehmendem Medium verhältnismässig einfach zu erkennen ist, liegen bei der Bestimmung der Verbrennungswärme im Explosionskalorimeter folgende Einflüsse vor:

Das Versuchsgas mit der Temperatur t wird mit Luft von der gleichen Temperatur t im einfachsten Falle gemischt in den Explosionsraum gebracht, dessen Wände, so wie die Glas- und Quecksilbermasse des in seiner Mitte befindlichen Thermometers ebenfalls die Temperatur t haben sollen. Durch die Zündung wird bei konstant gehaltenem Volumen v ein Temperaturstand t' erreicht, welcher bereits den Ausgleich der Wärme im ganzen System anzeigt. Durch die Verbrennung des Wasserstoffes in Gasgemischen sowie des Wasserstoffes in Gaskomponenten wird Wasserdampf erzeugt welcher auch schon im Momente der Entstehung kondensiert und dadurch einen Unterdruck im Explosionsraum bedingt. Da aber bei verschiedenen Gasen diese Wasserbildung je nach ihrer Zusammensetzung verschieden ist, und somit auch der nach der Explosion entstehende Unterdruck variabel ist, muss unmittelbar nach der Explosion durch Oeffnen eines Hahnes ein Ausgleich mit dem Aussendruck (Barometerstand) hergestellt werden.

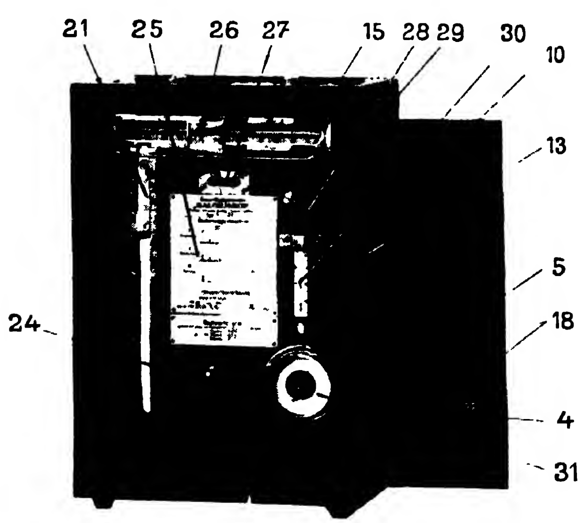
Diese, je nach dem Sauerstoffverbrauch und der eingetretenen Kondensation verschieden grosse zuströmende Luftmenge, die ein Maximum bei der Untersuchung reinen Wasserstoffes in der Nähe des theoretischen Mischungsverhältnisses erreicht, hat ebenfalls die Temperatur t und wird durch die Verbrennungsgase, sowie durch die Wärmeabgabe des ganzen Systems auf eine Temperatur gebracht, die man bei der Kleinheit der abzugebenden Wäımemenge ebenfalls mit genügend grosser Genauigkeit mit t' annehmen darf. Eine bei der Konstruktion resp. der Eichung des Instrumentes auszuschaltende Fehlerquelle bildet somit nur die variable Kondensationswärme, die im Falle des reinen Wasserstoffes ein Maximum, im Falle des reinen Kohlenoxyds ein Minimum = Null, erreicht. Wie in verschiedenen Veröffentlichungen bereits gezeigt werden konnte, hat es sich als praktisch herausgestellt, für die normalerweise zur Untersuchung in der Industrie gelangenden Gase (Generatorgas, Wassergas, Doppelgas, Mischgas, Produktionsgas), drei verschiedene Gas-Luft-Mischungsverhältnisse einzustellen und zwar: 1 : 3, 1 : 5, 1 : 7. Es wurde nun mit diesen drei Pipetten deren Volumina mit Quecksilber genau ausgemessen sind, deren Gas-Luft-Mischungsverhältnis somit auf drei Dezimalen genau bestimmbar ist, die Eichung des Instrumentes in der Weise durchgeführt, dass Pipette I (1 : 3) mit reinem Wasserstoff, Pipette II (1 : 5) mit reinem Wasserstoff sowie mit einem Methanwasserstoffgemisch, Pipette III (1 : 7) mit dem Gemisch der Pipette II sowie mit einem methanreicherem Gemisch geeicht wird. Dadurch wird der einzige, der sogenannte Kondensationsfehler des Instrumentes ausgeschaltet und eine Genauigkeit von *ein Drittel Prozent* erreicht.

Beschreibung

Der Apparat besitzt die geringsten Abmessungen eines Gasheizwertbestimmungsapparates (35 cm × 24 cm × 16 cm) sowie das geringste Gewicht (4 kg) und ist völlig transportsicher. Wie aus den beigefügten Abbildungen hervorgeht, wird das sich selbsttätig abmessende Gas, dessen Reduktionsbedingungen (Barometerstand, Gastemperatur, Wasserdampftension) das Kaloriskop ebenfalls anzeigt, durch ein auf einer Schiene leicht gleitendes Niveaugefäss durch gesenkten Wasserspiegel in den Explosionsraum, bereits gut mit Luft vermischt, übergeleitet und bei automatischer Sperre der Hähne durch einen Quecksilberkontakt eine sichere unfehlbare Zündung durch den Strom einer Taschenlampenbatterie, durch eine Induktionsspule verstärkt, bewirkt. Der Temperaturanstieg des

Thermometers, dessen Kugel sich inmitten des Explosionsraumes befindet, gibt das Mass für den Heizwert, der erhalten wird durch Multiplikation dieser Temperaturdifferenz mit dem Eichfaktor der verwendeten Pipette, sowie den aus den Angaben des Apparates errechenbaren Reduktionsfaktors. Die Bestimmung dauert ca. 3 Minuten, ist ohne Vorbereitungen durchführbar und der Höchststand des Thermometers nicht zu versäumen, da dieses sich in ca. 40 Sekunden dem Höchststand nähert und auf diesem ca. 20–30 Sekunden verharrt.

Durch ein Dewar'sches Vakuum vor Wärmeverlusten weitgehend geschützt, zeigt somit das Thermometer, dessen Quecksilbermasse ausser der thermometrischen Funktion gleichzeitig auch die kalorimetrische Substanz des Explosionsraumes vergegenwärtigt, den grössten Teil der erzeugten Wärme an, wobei durch die Eichung wie oben beschrieben eine Genauigkeit erreicht wird, welche das Instrument auch zu wissenschaftlichen Untersuchungen z.B. zur laboratoriumsmässigen Untersuchung der Schwelgase, zu Reinheitsprüfungen von Gasen geeignet macht.



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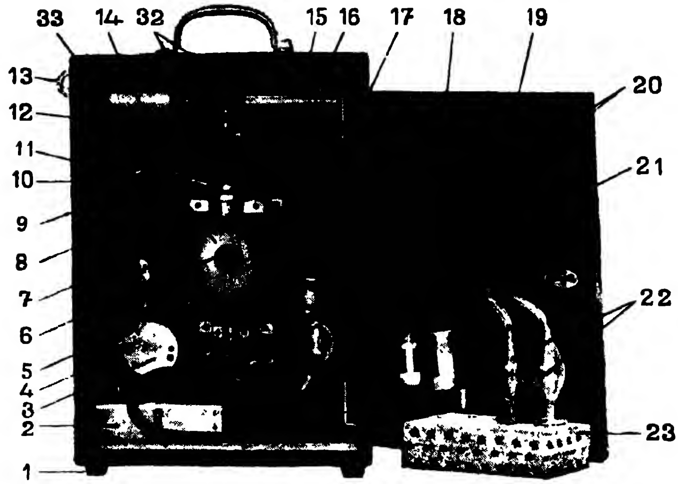

RÜCKANSICHT

1 Gummifusschen
2 Batterie samt Holzkastchen
3 Einstellschraube fur Barometer
4 Druckknopf fur Zundung (schwarz) und Druckknopf fur Beleuchtung (weiss)
5 Kapillare der Pipette
6 Explosionskugel im Dewarschen Vakuum
7 auswechselbare Pipette
8 Pipettenklammer.
9 Gummisicherung fur Hahn I
10 Filter und Gasanschluss.
11 Hahn I.
12 Stromzuleitung
13 Zugring fur Niveaugefass
14 Induktionsspule.
15 Explosionsthermometer
16 Schnurrolle
17 Gleitschiene fur Niveaugefass
18 Reservewatte und Öl
19 Kastenturchen, aushebbar, versperrbar.
20 Kontaktsperre fur Hahn II
21 Niveaugefass-Wasserstandrohr
22 Pipetten
23 Schachtel fur Pipetten
24 Hahn II.
25 Gebrauchsvorschrifttafel, Eichdaten.
26 Ableselupe, verschiebbar, auf Schiene.
27 Kontrollampchen (Argonröhre).
28 Hahnknopf I.
29 Schnurdurchlass.
30 Raumthermometer 1/10°.
31 Aneroidbarometer (wie 3).
32 Beleuchtungsvorrichtung.
33 Einsichtsfenster.

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RÉSUMÉ

(Specially prepared)

In 1909 Prof. Teclu constructed an apparatus, which for the first time determined the calorific and lighting value of gases by exploding them. Later, Strache invented an instrument in which a given quantity of gas was exploded and the heat generated measured from the expansion of the air. As these instruments, made of glass, broke easily and were too large to handle comfortably, they met with little support. A thermometer was employed later to determine the rise in temperature. Various constructional defects of these caloriscopes were responsible for errors up to 3 per cent.

The apparatus described here gives results within one-third per cent. accuracy. Whereas Strache's calorimeter did not permit variation in the mixture of gas and air, it was found that a calorimeter, suitable for all gases, must work with any standard mixture.

For the best results to obtain complete combustion, the explosion chamber, well insulated by Dewar's vacuum, should be spherical, the ignition taking place in the centre thereof.

The gas sample at a given temperature t is mixed with air of the same temperature t, and brought into the detonating chamber, the walls of which as well as the thermometer should have the same temperature t. After ignition, the temperature rises to t'. The combustion of hydrogen, present in the gas mixture, produces a certain amount of steam, which immediately condenses and thereby reduces the pressure. As the amount of water varies with the composition of the gas tested, the reduction in pressure will fluctuate as well; to normalise the pressure, a valve is opened immediately after the explosion. The heat required to raise the temperature of the additional air from t to t', on coming in contact with the rest of the system, is infinitesimal and can safely be ignored. Fluctuation in the heat generated during condensation is the sole cause of erratic measurement, which in the case of pure hydrogen reaches a maximum, and in the case of pure carbon monoxide is nil. Three ratios of gas and air mixtures have been found practicable for testing the principal gases used in industry, namely 1 : 3, 1 : 5 and 1 : 7. Three pipettes, the volume of which has been accurately determined with mercury, are calibrated as follows: No. 1 (1 : 3) with pure hydrogen, No. 2 (1 : 5) with pure hydrogen and a methane-hydrogen-mixture, No. 3 (1 : 7) with the mixture of pipette

No. 2 and a stronger methane-mixture. The only source of error is removed in this manner and an accuracy within one-third per cent. is obtained.

Facilities are also provided with this caloriscope for measuring air pressure, temperature of the gas and vapour pressure of the moisture. The gas, automatically measured and well mixed with air, is drawn into the explosion chamber by the movement of the water level. The valves are shut automatically and ignition is secured without risk of failure by a mercury contact. The necessary current is obtained from a pocket lamp battery, amplified by an induction coil. The rise in temperature registered on the thermometer, the bulb of which is placed in the centre of the detonating chamber, is multiplied by the calibration factor of the pipette used and the "reduction" factor, calculated from readings on the instrument.

No preparations are necessary for the operation, which is completed in about three minutes. The rise in temperature must be watched carefully as the maximum is reached in about forty seconds and remains stationary only for about twenty to thirty seconds.

The thermometer, well insulated by Dewar's vacuum, is graduated to indicate the calorific value of the gas present in the detonating chamber as well as the temperature rise. Nearly all the heat generated is recorded and by the calibration referred to above, an accuracy is obtained which permits the use of this instrument for scientific tests, such as the laboratory analysis of low-temperature distillation gases.

DIE UNTERSUCHUNG GASFÖRMIGER BRENNSTOFFE

(THE TESTING OF GASEOUS FUELS)

AUSTRIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

Paper No. H3

CONTENTS

PART I—BEITRÄGE ZUR TECHNISCHEN GASANALYSE

DR. H. LÖFFLER

Ein Referat über österreichische Arbeiten auf diesem Gebiete, im Jahre des Hinscheidens Hofrat Strache's vorgebracht, muss vor allem, ohne deswegen einseitig zu sein, dieses Mannes gedenken, der es sich unter anderem auch zur Lebensaufgabe gemacht hatte, für die Praxis und Industrie Behelfe zu schaffen, die durch ihre Einfachheit überall und an allen Stellen des Betriebes, nicht nur im Laboratorium, verwendet werden können, um aus der Zusammensetzung der Gase im Gaserzeugungsbetrieb, bezw. der Rauchgase, unmittelbare und daher desto wertvollere Schlüsse ziehen zu können.

Wenn auch die starke Arbeitsüberlastung Strache selbst verhindern musste, seine Ideen bis zur letzten Konsequenz und bis zur völligen Vermeidung aller Erzeugungsmängel zu verfolgen, so sind doch einige von ihnen in Apparaten verkörpert, die bis heute, also Jahre hindurch, in der Industrie mit grossem Nutzen in Verwendung stehen.

Feuerungskontrolle.—Die meisten Feuerungsanlagen bedürfen einer Einstellung hinsichtlich ihres Luftbedarfes, der oft sehr stark

überschritten wird. Bei Verwendung eines Brennstoffes bestimmter Zusammensetzung errechnet sich der theoretische Luftbedarf oder kann aus dem Verbrennungsdreieck nach Ostwald graphisch ermittelt werden. An Ueberwachungsapparaturen zur Prüfung der Kohlensäure in den Abgasen sowie zur Feststellung der Rauchgastemperatur gibt es eine Unmenge von Behelfen, die aber meistens folgende Nachteile aufweisen. Sie sind entweder viel zu teuer, um in kleine Betriebe eingestellt werden zu können, oder sie bestehen aus Glas und erheischen die Verwendung von Chemikalien, die öfters erneuert werden sollen, und das ist den in kleinen Betrieben beschäftigten Meistern oder Maschinenwärtern, schliesslich aber auch den Maschineningenieuren nicht sehr geläufig, so dass man fast immer die Beobachtung machen kann, dass derartige Apparate, wenn sie wirklich angeschafft werden, nach kurzer Zeit ausser Funktion gesetzt sind.

Ein Instrument, welches ganz aus Metall und Holz ist, daher als unzerbrechlich angesehen werden kann, ist der von Strache konstruierte Siccus, der seinen Namen dem hierin verwendeten trocknenen Absorbtionsmittel verdankt. Das Prinzip dieses Apparates besteht in der Verwendung eines Hahnes, dessen Bohrung als Pumpe ausgebildet ist, und mit welchem man ein der Bohrung entsprechendes, also konstantes Gasvolumen durch Saugen oder Drücken aufnimmt und dieses bei Hahndrehung mit dem Absorbtionsgefäss in Verbindung setzt. Die eintretende Volumsverminderung, hervorgerufen durch die Bindung der Kohlensäure, wird an einem Flüssigkeitsmanometer angezeigt, welches direkt auf Prozente Kohlensäure geeicht ist.

Die Temperaturmessung der Rauchgase oder technischen Gase im Gaserzeugungsbetrieb erfolgt häufig durch Fernanzeigeinstrumente der verschiedensten Prinzipien, die aber ebenfalls aus oben angeführten Gründen für kleine, ja auch für mittlere Betriebe nicht in Frage kommen. Anstelle dieser werden dafür an schwer zugänglichen Orten einfache Quecksilberthermometer angebracht und diese, wie sich aus der Praxis ergibt, von den Kesselwärtern oder Kontrollorganen, nur selten, auf besonders erteilten Auftrag abgelesen. Somit lag dringendes Bedürfnis für ein einfaches und billiges, aber doch zuverlässliches Temperaturfernanzeigeinstrument vor, dessen Lösung im Thermoskop gefunden wurde; dieses ist ein Quecksilberkontaktthermometer, wobei die Mängel dieser Instrumente, welche hauptsächlich darin bestehen, dass sich binnen Jahresfrist das Quecksilber durch die Kontaktfunken zum Teil verschmiert und einen Belag an der Thermometerkapillare bildet,

der dauernd Schluss verursacht, vermieden wurden. Ausserdem wurde in der Ausgestaltung darauf Rücksicht genommen, die Ablesung selbst recht deutlich zu machen, was durch Aufleuchten der betreffenden Temperaturanzeige auf einer leeren Mattscheibe erreicht werden konnte. Es wurde die Beobachtung gemacht, dass die Heizer und Maschinenwärter gerade diesem Instrument ihre Aufmerksamkeit zum Nutzen des Betriebes zuwenden.

Gaskontrolle.—Die in den Städten verlegten ausgebreiteten Gasrohrnetze, welche durch Jahrzehnte den Angriffen der Bodensäure, sowie der elektrischen Korrosion ausgesetzt sind, welch letztere sich besonders in der Nähe der Kabel der verschiedenen Stromleitungen bemerkbar macht, unterliegen der langsamen Zerstörung, welche Undichtheiten und Ausströmen des Gases zur Folge hat. Es ist oft sehr schwierig, diese undichten Stellen rasch herauszufinden und müssen deswegen oft unnütz weite Stellen des Strassennetzes freigelegt werden, wodurch bedeutende Kosten und Störungen des Verkehrs hervorgerufen werden. Das *Gasoskop* ist ein kleiner handlicher Apparat mit einer Empfindlichkeit, die bereits das Ausströmen von Gas in der Menge eines Liters pro Stunde deutlich erkennen lässt. Sein Prinzip ist einfach: eine feinporöse Tonmembrane, durch welche nach bekannten physikalischen Gesetzen die Gase umso rascher durchströmen, je geringer deren Dichte ist, ruft in einer Kammer, welche an einer Seite durch eine feine Metallmembrane abgeschlossen ist, einen Ueberdruck hervor, der von einem feinmechanischen Präzisionswerk auf einen Zeiger über einem Prozente anzeigenden Zifferblatt übertragen wird. Um nun Undichtheiten in Strassenleitungen rasch aufzufinden, genügt es, längs der Leitungsverlegung in Entfernungen von etwa 10 m Gasrohre, welche an einem Ende mit einem Hahn abschliessbar sind, anzubringen und mit dem Gasoskop nach einiger Zeit von Rohr zu Rohr zu gehen, und die Grösse der einzelnen Ausschläge am Zeiger zu beobachten; in der Nähe des stärksten Ausschlages ist die undichte Stelle.

Gasheizwert.—Bei Uebernahmsversuchen sowie bei Betriebskontrollen ist es erschwerend, das Junkershandkalorimeter zu verwenden, da dessen jedesmalige Montage mit Anschluss von Wasserzu- und -abfluss erstens nicht überall möglich, zweitens aber auf alle Fälle umständlich ist. Strache verwendete zum ersten Male das Prinzip der Heizwertbestimmung durch Verpuffung eines bestimmten Gasluftgemisches bei Uebertragung der freiwerdenden Wärme auf die Quecksilbermenge eines Thermometers, oder auch auf einen das Explosionsgefäss umgebenden Flüssigkeits- oder Gasmantel.

Apparate dieser Konstruktion, bekannt unter dem Namen Kaloriskop, finden heute bereits in fast allen Staaten Anwendung, da sie gestatten, den Heizwert jedes Gases von 900 Kalorien an bis zu 13 000 Kalorien in der Zeit von etwa 2 Minuten ohne irgendwelche Vorbereitungen bei einer Genauigkeit von $\frac{1}{3}$% zu bestimmen. Das Prinzip dieser Art der Heizwertbestimmung wurde vom Berichterstatter im letzten Lebensjahre Straches erweitert angewendet und die Konstruktion des Mikrokalorimeters geschaffen, mit welchem nicht nur wie oben der Heizwert jedes Gases, sondern auch dessen Grenzen der Explosionsfähigkeit sowie die Grenzen der vollkommenen Verbrennung bei einer Genauigkeit von $\frac{1}{3}$% mit einigen Kubikzentimeter Gas bestimmt werden können. Dadurch ist man nun in die Lage versetzt, die seinerzeit von Strache-Hiller angegebene sogenannte Röhrchenentgasung überhaupt erst in weiteren Kreisen durchzuführen. Diese Methode besteht darin, dass man in bestimmt geformten Röhrchen aus schwerschmelzbarem Glas 0,2 gr der Kohle einwiegt und bei Füllung des Röhrchenvolumens mit Stickstoff durch Erhitzen von aussen entgast. Das Gasvolumen, welches in der Menge von etwa 10-20 ccm anfällt, wird genau gemessen, indem man es über Kochsalz in der Buntebürette auffängt, dann mit Luft verdünnt (Nachspülung des im Röhrchen verbleibenden Gasrestes), und es kann schliesslich, nachdem man das Verdünnungsverhältnis festgelegt hat, im Mikrokalorimeter auf $\frac{1}{3}$% genau der Heizwertermittlung unterzogen werden. Es sei erwähnt, dass es auf diese Weise besonders leicht gelingt, die Braunkohlenschwelgase zu kalorimetrieren und dass hiedurch, was bereits mehrfach beschrieben wurde, eine fraktionierte Untersuchung der Schwelgase hinsichtlich ihres Heizwertes stattfinden kann.

Die Füllung des Mikrokalorimeters erfolgt mit Quecksilber, wobei durch Verwendung eines geschlossenen Kreislaufes das abgemessene Gas quantitativ in den Explosionsraum gebracht werden kann.

Es war mir eine besondere Pflicht, als ehemaliger Assistent Strache's bei Erstattung eines Referates über die Prüfung gasförmiger Brennstoffe, die hervorragende Rolle dieses Forschers, der der Wissenschaft leider zu früh entrissen wurde, besonders hervorzuheben, was umso eher geschehen durfte als die hier aufgezählten Instrumente, eine kleine Auswahl seiner Konstruktionen, weit über die Grenzen Österreichs bekannt geworden sind und sich steigender Beliebtheit in der Verwendung erfreuen.

PART II—METHODEN DER VERSUCHSANSTALT FÜR BRENNSTOFFE, FEUERUNGSANLAGEN UND GASBELEUCHTUNG AN DER TECHNISCHEN HOCHSCHULE IN WIEN

PROF. W. J. MÜLLER

An den genannten Instituten wird nur die technische Gasanalyse ausgeführt, die sich auf die Bestimmung der Kohlensäure, der schweren Kohlenwasserstoffe, des Sauerstoffs, des Kohlenoxyds, des Wasserstoffs, Methans und Stickstoffs erstreckt. Hiezu dienen hauptsächlich bei Vornahme der Untersuchung in Betrieben, also in Gaswerken oder bei Generatorenanlagen, die Apparaturen nach Bunte und Orsat, während im Laboratorium selbst meistens die Hempel'sche Gasanalyse zur Anwendung gelangt.

Zur Apparatur der wohl allgemein bekannten Hempel'schen Methode sind keine Erläuterungen erforderlich, wohl aber soll zu der im Institut verwendeten Apparatur nach Orsat und Bunte bemerkt werden, dass eine Bunte'sche Bürette mit dem Karlsruher Hahn verwendet wird, welche Bauart die bequeme Bestimmung der durch Verbrennung zu ermittelnden Gasbestandteile gestattet.

Bei der Orsatapparatur werden als Gaspipetten die nach dem Friedrichs'schen Schraubenprinzip gebauten Absorptionsgefässe verwendet. Als Bürette dient eine gleichweite, keinerlei Erweiterung aufweisende Gasbürette, welche 100 cm^3 fasst, in 0,2 cm^3 geteilt ist und noch 0,1 cm^3 festzustellen gestattet.

Bestimmung der einzelnen Gasbestandteile.—Die Kohlensäure wird durch Absorption mit Kalilauge 1 : 2 bestimmt. Die schweren Kohlenwasserstoffe absorbiert man bei Anwendung der Methode nach Bunte mit konzentriertem Bromwasser oder im Analysengang nach Hempel und Orsat mit rauchender Schwefelsäure. Die nicht absorbierten Gasreste enthalten sowohl bei Behandlung nach der einen wie nach der anderen Methode noch Reste des Absorptionsmittels, die durch Waschen mit Kalilauge entfernt werden müssen.

Der Sauerstoff wird ausschliesslich mit Pyrogallol absorbiert, welches bei Einhaltung folgender Bereitungsvorschrift der Lösung angewendet nicht die Nachteile der übrigen Absorptionsmittel, wie elementarer Phosphor und Natriumhydrosulfit, besitzt. Eine 20%ige Lösung von Pyrogallal mit 5-6 Teilen einer Kalilauge 3 : 2 gemischt gibt nach den Untersuchungen von Ott in Zürich die am besten brauchbare Lösung.

Kohlenoxyd wird quantitativ nur durch eine ammoniakalische

Lösung von Kupferchlorür absorbiert, während salzsaure Kupferchlorürlösung nur zur Absorption der Hauptmenge des Kohlenoxyds dienen könnte. Es werden normaler Weise 2 Pipetten zur Absorption des Kohlenoxyds benützt und zwar dient die eine mit schon gebrauchter Kupferchlorürlösung zur Absorption der Hauptmenge, während die Reste des Kohlenoxyds nur mit ganz frischer Lösung aus dem Gas herausgewaschen werden. Die Zusammensetzung des Gasrestes, welcher noch aus Wasserstoff, Methan und Stickstoff besteht, wird durch fraktionierte Verbrennung bestimmt.

Die Anwendung der Explosionsmethode ist entschieden unrichtig, da bei einem Gas unbekannter Zusammensetzung niemals die richtigen Gassauerstoff- oder Gasluftgemische hergestellt werden können, welche eine vollständige Verbrennung des Gasgemisches gewährleisten. Vielmehr wird heute ausschliesslich nur die Methode der fraktionierten Verbrennung angewendet und zuerst der Wasserstoff bei 295° mit einer gemessenen Menge Sauerstoff über gekörntem Kupferoxyd, welches sich in einem Quarzröhrchen befindet, verbrannt. Der Gasrest von Methan wird nach Löwy in einer Quarzkapillare, in welche ein elektrisch auf hellrote Glut heizbarer Platindraht eingebaut ist, mit Sauerstoff verbrannt. Enthält das Gas ausser Methan auch noch Aethan, so macht sich dessen Gegenwart durch die reinem Methan nicht entsprechende Kontraktion im Vergleich zu dem gefundenen Kohlensäuregehalt bemerkbar, wodurch sich die Aethanmenge berechnen lässt. Als unverbrennbarer Gasrest ergibt sich dann nur Stickstoff, dessen Gehalt aber auch direkt durch Gesamtverbrennung aller mit Sauerstoff reagierenden Gaskomponenten durch Verbrennen über Platin bestimmbar ist. Aus der darauf folgenden Kohlensäureabsorption kann der Kohlenstoffgehalt des Gases per m^3 und auch sein Stickstoffgehalt unmittelbar berechnet werden.

RÉSUMÉ

(*Specially prepared.*)

PART I.—CONTRIBUTION ON TECHNICAL GAS ANALYSIS

Apparatus constructed mainly in accordance with the ideas and designs of the late Professor Strache is described.

In contra-distinction to a variety of instruments on the market, these attempt to meet the requirements of small concerns, both in regard to price and simplicity.

Strache's "Siccus," which is of sound engineering construction, is employed in the determination of carbon dioxide. By the action of a pump a quantity

of gas, the volume of which is relative to the size of the pump and, therefore, constant, is drawn through a valve and then brought into connection with the absorbtion tube. The reduction of volume, resulting from the fixation of the carbon dioxide, is registered on a manometer (liquid) calibrated to show directly the percentage of carbon dioxide.

The "Thermoscope" is an instrument specially constructed to take temperature readings of gases at inaccessible places.

The "Gasoscope" is a small cell, one side of which is a fine porous diaphragm, the other is a metal diaphragm attached to a delicate indicating device. It is used to locate leakages from defective gas mains.

An instrument known as the "Caloriscope" determines the calorific value of gases by means of explosion methods. It can be used with any gas and gives results with an accuracy within one-third per cent. The operation requires about two minutes, there being no preparations. The same principle was employed by the writer and led to the construction of the "Microcalorimeter," which gives an accuracy within one-third per cent. with a few cubic centimetres of gas. This improvement brings Strache's gasification assay tube into a more general application; 0·2 gr. coal is gasified in a specially constructed tube, filled with nitrogen. The gas (about 20 to 30 cu. cm.) is accurately measured by collecting in a Bunte-burette over salt solution. After diluting with air and determining the amount of dilution, the calorific value is ascertained. This method is very suitable for testing low temperature distillation gases from brown coal, as a fractional analysis of their calorific value is possible.

Part II.—Review of the Methods Employed for Investigation of Fuels, Firing and Gas Lighting in the Technical University, Vienna.

For works' tests, such as those carried out in gasworks or with producers, apparatus by Bunte and Orsat is principally used, whereas for laboratory tests Hempel's apparatus is employed. The Bunte-burette is fitted with the Karlsruhe-tap, facilitating determination of the gas components obtained by combustion. Absorbtion pipettes constructed on Friedrichs' spiral principle are used with the Orsat apparatus.

The usual absorbents are employed; potash solution for carbon dioxide, concentrated bromide solution for the hydrocarbons, which can also be determined by Hempel and Orsat analysis with fuming sulphuric acid. Pyrogallol is used for oxygen, whereas carbon monoxide is absorbed with a solution of ammoniacal cuprous chloride.

The components of the remaining gas, hydrogen, methane and nitrogen, are determined by fractional combustion. The determination of these by explosion methods is incorrect, as with a gas, the composition of which is unknown, the required ratio of gas and air cannot be calculated and complete combustion satisfactorily obtained.

DIE FÜR DIE VERBRENNUNG BESTIMMENDEN EIGENSCHAFTEN DER GASE

(THE PROPERTIES OF GASES DEFINING THEIR COMBUSTION)

DEUTSCHER VEREIN VON GAS- UND WASSERFACHMÄNNERN

DR. W. BERTELSMANN UND DR. F. SCHUSTER

Paper No. H4

CONTENTS

Verbrennung nennt man die Vereinigung von Stoffen mit Sauerstoff; praktisch engt sich der Begriff auf kohlenstoff- und oder wasserstoffhaltige Substanzen und Luft ein. Wenn die Oxydation vollständig ist, so enthalten die Verbrennungsprodukte nur Kohlensäure, Wasser und Stickstoff, falls mit gerade ausreichender Luftmenge verbrannt wird; erfolgt die vollkommene Verbrennung mit Luftüberschuss, dann enthalten die Verbrennungsprodukte ausser den drei vorerwähnten Stoffen noch Sauerstoff. Bei unvollkommener Verbrennung führt die Oxydation nur zu niedrigeren Oxydationsstufen (CO) oder ein Teil des Brenngases blieb überhaupt unverbrannt. Als chemische Reaktion wird die Verbrennung von einer (positiven) Wärmetönung begleitet, die weitgehende Ausnutzung findet. Wird die Wärmetönung vorzugsweise zum Erzeugen von möglichst hohen Temperaturen benutzt, so spricht man von *pyrometrischem*, andernfalls von *energetischem* oder *kalorischem* Effekt; praktisch vermischen sich diese beiden mehr oder minder hypothetischen Grenzfälle.

Hieraus ergeben sich die für die Verbrennung im allgemeinen bestimmenden Eigenschaften, die im folgenden mit Bezug auf die gasförmigen Brennstoffe betrachtet werden sollen. Diese

Eigenschaften sind: *Verbrennungswärme bzw. Heizwert* (Wärmetönung der als Verbrennung bezeichneten Reaktionen), *Luftbedarf, Zusammensetzung und Menge der Verbrennungsgase, Verbrennungstemperatur* bzw. *Flammentemperatur, Verbrennungsgeschwindigkeit, Entzündungstemperatur* und *Entzündungsgeschwindigkeit, Explosionsgrenzen* und *-geschwindigkeit.*

Von den für die Verbrennung bestimmenden Eigenschaften der Gase sind die wichtigsten, wie Heizwert bzw. Verbrennungswärme, von der absoluten Gasmenge abhängig, weshalb man sie auf die Mengeneinheit bezieht. Gasmengen werden selten in Masseneinheiten (kg-Masse), meist in Raumeinheiten (m^3) angegeben. Der Raum, den ein Gas einnimmt, wechselt verhältnismässig stark, jedoch gesetzmässig mit dem darauf lastenden Druck, der Temperatur und dem Feuchtigkeitsgehalt. In der Praxis werden Gase unter wechselnden Drücken, verschiedenen Temperaturen und schwankendem Wasserdampfgehalt gemessen, so dass die gemessenen Mengen nicht unmittelbar vergleichbar sind. Deshalb einigte man sich dahin, die unter beliebigen Zustandsbedingungen gemessenen Gasmengen auf bestimmte Normalbedingungen umzurechnen. Als solche galten früher in Deutchland allgemein die Temperatur von 0°C, der Druck von 760 mm QS und der Zustand der Trockenheit. Diese Bedingungen, von den wissenschaftlichen Arbeiten für die technische Praxis entlehnt, treten dort fast nie auf, weshalb ein "Normalzustand" geeigneter erschien, der den durchschnittlichen praktischen Verhältnissen näher kam. Als Temperatur wurde 15°C gewählt, der Druck von 760 mm QS konnte bleiben, dagegen sollten die Gase mit Wasserdampf gesättigt sein, doch bürgerte sich dieser Normalzustand bisher noch nicht recht ein.

Die Grundlage für alle Umwandlungen der Gase bilden neben dem fundamentalen Gesetz von Avogadro (1811) die Regeln von Gay-Lussac, bzw. Charles (1802), Boyle-Mariotte (1662) und Dalton (1807). Darnach berechnet sich ganz allgemein der von einem Gas unter dem Druck P_n, der Temperatur t_n °C mit einem bestimmten Wasserdampfgehalt, dessen Partialdruck w_{tn} ist, eingenommene Raum, wenn die Gasmenge bei dem reduzierten Barometerstand B, unter einem Ueberdruck p gegen die Atmosphäre gemessen, der Temperatur t°C und einem Wasserdampfgehalt mit dem Partialdruck w_t bestimmt wird, zu

$$V_{Pn,\,tn,\,\text{feucht}} = V_{Pt,\,\text{feucht}} \cdot \frac{\overbrace{B+p}^{P} - w_t}{P_n - w_{tn}} \cdot \frac{273 + t_n}{273 + t} \qquad (1)$$

Ist das betrachtete Gasvolumen mit Wasserdampf gesättigt, dann bedeuten w_t und w_{t_n} die Sättigungsdrucke des Wassers für die Temperaturen t und t_n. Soll das Gas bei t oder t_n trocken sein, so verschwindet der betreffende w-Wert aus der Gleichung (1). Alle Drucke werden im gleichen Massystem (mm QS) ausgedrückt.

Die allgemeine Formel nimmt für die "Normalzustände" folgende besondere Formen an :

$$V_{760,\ 0°,\ \text{trocken}} = V_{P,\ t,\ \text{feucht}} \cdot \overbrace{\frac{B + p - w_t}{273 + t} \cdot 0{,}3592}^{=A} \qquad (2a)$$

$$\text{und} \quad V_{760,\ 15°,\ \text{feucht}} = V_{P,\ t,\ \text{feucht}} \cdot \underbrace{\frac{B + p - w_t}{273 + t} \cdot 0{,}3854}_{=A'} \qquad (2b)$$

Zur "Reduktion' der Gasvolumina, wie diese Umrechnungen heissen, dienen Tabellen, welche die Werte von A [1]) oder A' [2]) für verschiedene Temperaturen und Druck enthalten.

Die Gleichungen (2a) und (2b) unterscheiden sich voneinander nur durch die Grösse der Koeffizienten ; es besteht die Beziehung

$$V_{760,\ 0°,\ \text{trocken}} : V_{760,\ 15°,\ \text{feucht}} = 0{,}3592 : 0{,}3854$$
$$1 : 1{,}073$$
$$0{,}932 : 1$$

Die Beziehung besagt, dass 1 m³ von 760 mm QS, 0°C, trocken 1,073 m³ bei 760 mm QS, 15°C, feucht einnimmt, oder umkehrt 1 m³ von 760 mm QS, 15°C, feucht 0,932 m³ bei 760 mm QS, 0°C, trocken. Im gleichen Masse ändern sich jene Eigenschaften, die von der Gasmenge abhängen.

Unter *Verbrennungswärme* versteht man jene Wärmemenge, die der Oxydationsvorgang insgesamt liefert, wenn die Temperatur aller beteiligten Produkte vor und nach dem Prozess dieselbe ist. Die Ausgangstemperatur beeinflusst den absoluten Wert der Verbrennungswärme innerhalb nicht zu weiter Temperaturgrenzen nur wenig. Dagegen ist bei wasserstoffhaltigen Brennstoffen von Einfluss, ob das durch die Verbrennung entstandene Wasser dampfförmig bleibt oder sich flüssig niederschlägt. Führt die Verbrennung zu *flüssigem* Wasser, so muss zur eigentlichen Reaktionswärme die freiwerdende Kondensationswärme ($\mp$ gleich der Verdampfungswärme) zugezählt werden ; der so erhaltene Wert, der *obere Heizwert* oder die (eigentliche) *Verbrennungswärme*, ist um diesen

[1] *Junkers, Ludwig.*
[2] *R. Geipert.*

Betrag grösser als der *untere Heizwert*, der das Verbrennungswasser als dampfförmig voraussetzt und praktisch meist in Frage kommt. Die oberen und unteren Heizwerte von Gasgemischen, und solche sind die technischen Brenngase (Leuchtgas, Wassergas, Generatorgas u. dgl.) fast ausschliesslich, setzen sich aus den entsprechenden Werten der reinen Bestandteile additiv zusammen, wobei die Werte proportional den Volumanteilen zu nehmen sind.

Bei Kenntnis des oberen Heizwerts eines Gases (bezogen auf 0°C, 760 mm QS, trocken) berechnet man den unteren, indem man je m^3 H_2 485 kcal vom ersteren abzieht Die Verdampfungswärme des Wassers beträgt bei gewöhnlichen Temperaturen für 1 kg 606 kcal, rund 600 kcal. Da 1 m^3 H_2, gleichgültig ob als freier Wasserstoff oder in chemischer Verbindung, 804 g Wasser gibt, so müssen rund 485 kcal abgezogen werden. Der obere Heizwert des Propans, C_3H_8, ist 23 500 kcal/m^3; wenn im folgenden nichts anderes vermerkt, so ist m^3 von 0°C, 760 mm QS, trocken zu verstehen. Weil das Propan $4 \cdot H_2$ enthält, sind $4 \cdot 485 = 1\,940$ kcal abzuziehen, was einen unteren Heizwert von 21 560 kcal/m^3 gibt. Die folgende Zahlentafel bringt die Heizwerte für eine Reihe wichtiger Gase (und Dämpfe).

	oberer Heizwert in kcal je m^3 (0°C, 760 mm QS, tr.)	unterer Heizwert in kcal je m^3 (0°C, 760 mm QS, tr.)
H_2	3 055	2 670
CO	3 035	3 035
CH_4	9 530	8 560
C_2H_6	16 550	15 095
C_3H_8	23 500	21 560
C_2H_4	15 380	14 410
C_2H_2	13 900	13 415
C_6H_6 (Dampf) ...	34 865	33 410

Als Beispiel werde der Heizwert eines Koksofengases folgender Zusammensetzung berechnet :

		H_o	H_u
CO_2	.... 2% ...	—	—
CO	.... 5% ...	5·30,35 = 152	5·30,35 = 152
H_2	.........58% ...	58·30,55 = 1 772	58·26,70 = 1 549
CH_4	.........25% ...	25·95,30 = 2 383	25·85,60 = 2 140
C_2H_4	.... 3% ...	3·153,80 = 461	3·144,10 = 432
N_2	.... 7% ...	—	—
		4 768	4 273

H_o = 4 770 kcal/m^3,
H_u = 4 270 kcal/m^3.

Der Unterschied zwischen oberem und unterem Heizwert kann für Kohlendestillationsgase, wie auch das Rechenbeispiel zeigt, zu etwas mehr als 10% von H_o angenommen werden, was die angenäherte Berechnung von H_u aus H_o ermöglicht.

In der Praxis legt man grosses Gewicht darauf, den Heizwert von Brenngasen möglichst gleichmässig zu halten, weil jede gröbere Aenderung eine Umstellung der auf ein Gas mit bestimmtem Heizwert eingestellten Gasgeräte erforderlich macht, wodurch dem das Gas verfeuernden Betrieb Schwierigkeiten erwachsen. Am stärksten beeinflussen den Heizwert jene Bestandteile, die selbst sehr heizkräftig sind, also Benzoldämpfe, Aethylen usw.; schwankt deren Menge verhältnismässig wenig im Gas, so tritt schon eine beträchtliche Aenderung des Heizwertes ein [3]). Auch in anderer Hinsicht wirken die sogenannten "schweren Kohlenwasserstoffe" ungünstig auf die Gleichmässigkeit der Eigenschaften ein, worauf noch später hingewiesen wird.

Zur vollständigen Verbrennung braucht jeder Brennstoff eine gewisse Sauerstoffmenge. Da man praktisch nicht mit reinem Sauerstoff sondern mit Luft verbrennt und die Luft ein Sauerstoff-Stickstoff-Gemisch von unveränderlicher Zusammensetzung ist (sie besteht aus 21 Volum-% O_2 und 79 Volum-% N_2), so kann man sich unmittelbar auf die Luftmenge beziehen; 4,76 m^3 Luft enthalten 1 m^3 Sauerstoff. Die zur vollständigen Verbrennung gerade ausreichende Luftmenge wird als *Luftbedarf* bezeichnet. Wenn weniger Luft vorhanden ist als die theoretische Menge, so bleibt die Verbrennung aus Luftmangel oder Luftunterschuss unvollkommen. In der Praxis wird meist mit Luftüberschuss verbrannt. Der Luftüberschuss, das Verhältnis zwischen tatsächlich zugeführter zu theoretisch notwendiger Luftmenge, soll bei Gasheizung 1,2 bis 1,3 betragen.

Der Luftbedarf errechnet sich leicht aus den Verbrennungsgleichungen, bzw. aus der Zusammensetzung des Brennstoffs. Für jedes C-Atom müssen je m^3 Brenngas 4,76 m^3 Luft theoretisch zugeführt werden, für jedes H_2-Molekül 2,38 m^3; dagegen sind für jedes schon vorhandene O_2-Molekül 4,76 m^3 abzuziehen. Die folgende Zusammenstellung enthält einige praktische wichtige Werte:

	Luftbedarf in m^3 je m^3 Gas
H_2	2,38
CO	2,38
CH_4	9,52
C_2H_6	16,66
C_3H_8	23,80
C_2H_4	14,28
C_2H_2	11,90
C_6H_6 (Dampf)	35,70

[3] Vgl. *D. Stavorinus*, Het Gas *48*, 5 (1928).

Der Luftbedarf eines gemischten Brenngases errechnet sich wieder additiv aus dem der einzelnen Bestandteile und beträgt für das früher erwähnte Koksofengas 4,31 m.[3]

Die *Zusammensetzung der Verbrennungsgase* der vollständigen Verbrennung wechselt qualitativ und quantitativ mit der Art des Brennstoffs. Reiner Kohlenstoff liefert bei Verbrennung mit der gerade ausreichenden Menge trockener Luft ein Abgas, das aus 21% Kohlensäure und 79% Stickstoff besteht, weil jeder Raumteil Sauerstoff durch den gleichen Raumteil Kohlensäure ersetzt wird. Die gasförmigen Brennstoffe ergeben je nach ihrer Zusammensetzung wechselnde Abgase, doch liegt deren Kohlensäuregehalt, auf trockenes Abgas berechnet, stets unter 21%, mit alleiniger Ausnahme des Kohlenoxyds. Dieses enthält schon einen Teil des Sauerstoffs ohne das der Luftzusammensetzung entsprechende Stickstoffäquivalent. Wird reines Kohlenoxyd mit gerade ausreichender Luftmenge verbrannt, dann steigt der Kohlensäuregehalt auf 34,7% neben 65,3% Stickstoff. Ein anderes Bild liefern Gase mit wasserstoffhaltigen Bestandteilen. Reiner Wasserstoff verbrennt zu Wasser und Stickstoff:

$$2\,H_2 + \underbrace{O_2 + 3{,}76\,N_2}_{=\,\text{Luft}} = 2\,H_2O + 3{,}76\,N_2,$$

das trockene Verbrennungsgas ist somit reiner Stickstoff. Die gewöhnlichen Gasanalysen (Orsat usw.) geben stets die Zusammensetzung der *trockenen* Gase. Menge und Zusammensetzung der Verbrennungsgase der wichtigsten brennbaren Gase zeigt die folgende Zusammenstellung:

	Menge der Verbrennungsgase in m³ je m³ Brenngas		Zusammensetzung der Verbrennungsgase	
	feucht	trocken	feucht	trocken
H_2	1,88 N_2 1 H_2O 2,88	1,88 N_2	65,3% N_2 34,7% H_2O	100% N_2
CO	—	1,88 N_2 1 CO_2 2,88	—	65,3% N_2 34,7% CO_2
CH_4	7,52 N_2 1 CO_2 2 H_2O 10,52	7,52 N_2 1 CO_2 8,52	71,5% N_2 9,5% CO_2 19,0% H_2O	88,3% N_2 11,7% CO_2

	Menge der Verbrennungsgase in m^3 je m^3 Brenngas		Zusammensetzung der Verbrennungsgase	
	feucht	trocken	feucht	trocken
C_2H_6	13,16 N_2 2 CO_2 3 H_2O 18,16	13,16 N_2 2 CO_2 15,16	72,5% N_2 11,0% CO_2 16,5% H_2O	86,8% N_2 13,2% CO_2
C_3H_8	18,8 N_2 3 CO_2 4 H_2O 25,8	18,8 N_2 3 CO_2 21,8	72,9% N_2 11,6% CO_2 15,5% H_2O	86,2% N_2 13,8% CO_2
C_2H_4	11,28 N_2 2 CO_2 2 H_2O 15,28	11,28 N_2 2 CO_2 13,28	73,8% N_2 13,1% CO_2 13,1% H_2O	84,9% N_2 15,1% CO_2
C_2H_2	9,4 N_2 2 CO_2 1 H_2O 12,4	9,4 N_2 2 CO_2 11,4	75,8% N_2 16,1% CO_2 8,1% H_2O	82,5% N_2 17,5% CO_2
C_6H_6 (Dampf)	28,95 N_2 6 CO_2 3 H_2O 37,95	28,95 N_2 6 CO_2 34,95	76,3% N_2 15,8% CO_2 7,9% H_2O	82,8% N_2 17,2% CO_2

Menge und Art der Verbrennungsgase eines gemischten Brenngases berechnen sich wieder aus den bezüglichen Werten ihrer Bestandteile. Greifen wir auf das frühere Beispiel des Koksofengases zurück, so ergibt sich:

2% CO_2	$\rightarrow$		0,02 m^3 CO_2	
5% CO	$\rightarrow$	0,094 m^3 N_2 +	0,05 m^3 CO_2	
58% H_2	$\rightarrow$	1,0904 m^3 N_2		+ 0,58 m^3 H_2O
25% CH_4	$\rightarrow$	1,88 m^3 N_2 +	0,25 m^3 CO_2 +	0,50 m^3 H_2O
3% C_2H_4	$\rightarrow$	0,3384 m^3 N_2 +	0,06 m^3 CO_2 +	0,06 m^3 H_2O
7% N_2	$\rightarrow$	0,07 m^3 N_2		
		3,4728 m^3 N_2 +	0,38 m^3 CO_2 +	1,14 m^3 H_2O

Es entstehen 4,993 m^3 feuchte Verbrennungsgase mit 69,6% N_2, 7,6% CO_2, 22,8% H_2O bzw. 3,853 m^3 trocken mit 90,1% N_2 und 9,9% CO_2.

Der Höchstkohlensäuregehalt technischer gasförmiger Brennstoffe schwankt mit der Zusammensetzung, liegt jedoch stets unter 21%; z.B. ist er für Stadtgas etwa 12%, für Generatorgas rd. 20%. Praktisch enthalten die Verbrennungsgase den Sauerstoff des

Luftüberschusses. Während sich bei Verbrennung von reinem Kohlenstoff CO_2- und O_2-Gehalt stets auf 21 ergänzen, liegt diese Summe für die technischen Brenngase zwischen dem Höchstkohlensäuregehalt und dem Wert 21 (reine Luft). Zur angenäherten Ermittlung der Verbrennungsgaszusammensetzung (trocken) allein aus dem Kohlensäuregehalt dienen das Buntediagramm oder darnach aufgestellte Zahlentafeln [4]).

Als theoretische *Verbrennungstemperatur* (auch *Flammentemperatur*) wird jene Temperatur verstanden, die das Abgasgemisch erreicht, wenn die ganze freiwerdende Wärme ausschliesslich zu seiner Erwärmung dient, ohne dass Wärme durch Abstrahlung oder Leitung nach aussen abgegeben wird ("adiabatische" Verbrennung). Die durch den unteren Heizwert dargestellte Wärmemenge ist dann gleich der fühlbaren Wärme der Verbrennungsgase.

Die theoretische Verbrennungstemperatur wird nach der Formel

$$t = \frac{H_u + Q}{AC_A + BC_B + CC_C} \tag{3}$$

berechnet. Darin bedeuten

H_u den unteren Heizwert
Q die fühlbare Wärme des Brenngases und der Verbrennungsluft vor der Verbrennung (Vorwärmung);
A m³ $O_2 + N_2$ |
B m³ CO_2 | der je m³ Brenngas entstehenden Verbrennungsgase
C m³ H_2O-Dampf |
C_A, C_B, C_C die mittleren spezifischen Wärmen der Verbrennungsgasbestandteile unter konstantem Druck bei der Verbrennungstemperatur t.

Da sich die Werte der spezifischen Wärmen mit der Temperatur ändern, muss man zunächst gefühlmässig eine Verbrennungstemperatur wählen, die zugehörigen Werte dafür in (3) einsetzen und damit t berechnen; für die so erhaltene Temperatur setzt man die nunmehr gültigen Werte ein, erhält wieder eine Temperatur t und fährt in dieser Art so lange fort, bis genügende Uebereinstimmung erzielt wird.

Die mittleren spezifischen Wärmen zwischen 0° und t°C betragen nach Neumann [5])

	CO_2 SO_2	H_2O-Dampf	N_2, O_2, CO, Luft
0°C	0,397 kcal/m³	0,372 kcal/m³	0,312 kcal/m³
500	0,467	0,380	0,322
1 000	0,511	0,398	0,332
1 500	0,536	0,424	0,342
2 000	0,556	0,465	0,352
2 500	0,570	0,516	0,362
3 000	0,581	0,573	0,372

[4] *F. Schuster*, Feuerungstechnik, *16*, 54 (1928).
[5] *B. Neumann*, Journal für Gasbeleuchtung *62*, 606 (1919).

Das mehrmalige Probieren macht die Berechnung ziemlich umständlich. Schack [6]) stellte die spezifischen Wärmen durch Gleichungen von der Form $a - \frac{b}{t}$ dar, setzte diese in (3) ein und erhielt folgende einfache Formeln:

für eine Verbrennungstemperatur zwischen 800° und 1 800°:

$$t = \frac{H_u + Q + 32A + 80B + 75C}{0{,}364A + 0{,}591B + 0{,}477C}; \qquad (4a)$$

für 1 700° und 2 800°C

$$t = \frac{H_u + Q + 93{,}5A + 128B + 448C}{0{,}400A + 0{,}621B + 0{,}695C}. \qquad (4b)$$

Die einzelnen Zeichen haben die gleiche Bedeutung wie in Gleichung (3). Die so erhaltenen Verbrennungstemperaturen stimmen mit den durch Probieren erhaltenen auf $\pm\frac{1}{2}\%$ überein. Zur Berechnung braucht man nur den unteren Heizwert und die Abgasanalyse zu kennen. Im folgenden sind einige so berechnete Werte zusammengestellt

		1 000 · (Abgasmenge : H_u)
H_2	2 205°C	1,08
CO	2 430	0,95
CH_4	2 050	1,23
C_2H_6	2 085	1,20
C_3H_8	2 095	1,20
C_2H_4	2 325	1,06
C_2H_2	2 635	0,92
C_6H_6	2 200	1,14

Die Verbrennungstemperatur wird nicht unmittelbar durch den Heizwert bestimmt, sondern sehr angenähert durch das Verhältnis von Abgasmenge zu Heizwert, wie die obige Zahlenreihe zeigt. Je mehr Abgase, also je grösser dieser Quotient, umso niedriger die Verbrennungstemperatur, und umgekehrt. Die Verbrennungstemperatur eines Gemisches ergibt sich nicht additiv aus den Bestandteilen, was schon aus der Formel hervorgeht. Für das früher erwähnte Koksofengas finden wir t = 2 315°C und den Quotienten zu 1,17.

Diese Verbrennungstemperaturen werden alle unter der Annahme berechnet, dass die Abgasbestandteile keine thermische Dissoziation erleiden. Da aber sowohl Kohlensäure als auch Wasserstoff bei Temperaturen über 1 700°C merklich dissoziiert sind, so erleiden die Werte einige Veränderung. Die Dissoziationswerte für Kohlensäure und Wasserdampf wurden von Nernst und seinen Schülern [7])

[6] *A. Schack*, Mitteilungen der Wärmestelle Düsseldorf des Vereins deutscher Eisenhüttenleute Nr. 87.

[7] *W. Nernst*, theoretische Chemie, 8. bis 10. Aufl. S.763, Stuttgart 1921.

berechnet. Schack [8]) hat Berechnungsformeln unter Berücksichtigung der Dissoziation abgeleitet und auch angewandt. Mit Hilfe dieser Gleichungen wurde vergleichsweise die Verbrennungstemperatur von Wasserstoff und Kohlenoxyd berechnet:

	ohne Dissoziation	mit Dissoziation
H_2	2 205°C	2 145°C
CO	2 430°C	2 095°C

Diese Werte bestätigen die Erfahrungen, wonach mit Wasserstoff-Flammen höhere Temperaturen erhalten werden als mit Kohlenoxydflammen.

Die *Verbrennungsgeschwindigkeit* hängt wesentlich von Flammentemperatur, Wärmeleitungsvermögen, Entzündungstemperatur und spezifischer Wärme ab. Sie ist am grössten für H_2, am kleinsten bei CO, u.z. in Mischung mit Sauerstoff für H_2 20 m/sec, für CO 2 m/sec. Sie wechselt mit dem Verhältnis Brenngas : Verbrennungsluft und erreicht den Maximalwert für die Gemische mit der theoretischen Zusammensetzung. Bei Wasserstoff ist als einzige Ausnahme ein geringer Wasserstoffüberschuss günstig. Durch Verbrennung mit Luft sinkt die Geschwindigkeit auf 2 m/sec für H_2 und 0,3 m/sec für CO [9]).

Entzündungstemperatur ist jene Temperatur, bei der ein Gas in Sauerstoff oder Luft sich entzündet, ohne freie Flamme. Sie wurde von *Dixon* und *Coward* [10]) für einige Gase bestimmt, die folgende Mittelwerte fanden:

	in O_2	in Luft
H_2	585°C	585°C
CO	650	651
CH_4	556—700	650—750
C_2H_6	520—630	520—630
C_3H_8	490—570	—
C_2H_4	510	540
C_2H_2	428 (?)	429

Unter *Entzündungsgeschwindigkeit* von Gasen versteht man die Geschwindigkeit, mit der sich die Zündung im Gasgemisch fortpflanzt. Sie hängt ab von der Verbrennungswärme, der Wärmeleitfähigkeit, der spezifischen Wärme, der Anfangstemperatur und der Entzündungstemperatur des Frischgases. *Nusselt* [11]) hat für ihre Berechnung folgende Formel angegeben:

$$w = \sqrt{\frac{c_1 \cdot \gamma p_o \cdot T_o^2 (T_v - T_c) G_2^\circ O_2^\circ}{103{,}7 \cdot R^2 \cdot c_p (T_c - T_o)}}$$

[8] *A. Schack*, Mitteilungen der Wärmestelle Düsseldorf des Vereins deutscher Eisenhüttenleute Nr. 79.
[9] *Hofsäss*, Journal für Gasbeleuchtung *62*, 545 (1919).
[10] *Dixon* u. *Coward*, Journal of the Chemical Society *95*, 514 (1909).
[11] *Nusselt*, Z.d.V D.I. (1915).

Hierin bedeutet:

w = Zündgeschwindigkeit in m/sec.
γ = mittlere Wärmeleitzahl des Gasgemisches.
p_o = Druck.
T_o = Anfangstemperatur.
T_c = Entzündungstemperatur
T_v = Verbrennungstemperatur.
G_2° = Raumteile Gas vor der Verbrennung.
O_2° = Raumteile Sauerstoff vor der Verbrennung.
c_p = mittlere spezifische Wärme der Raumeinheit Gasgemisch zwischen T_c und T_v bei 15° und 1 atü.
R = Gaskonstante.
c_1 = Konstante, durch Versuch zu ermitteln.

Experimentalarbeiten über die Entzündungsgeschwindigkeit von Gasen sind von folgenden Forschern ausgeführt worden: *Ubbelohde* und *de Castro*[12]), *Hofsäss*[13]), *Dommer*[14]), *Koellicker*[15]), *Anwandter*[16]), *Stedirg*[17]). Diese haben ergeben, dass *Nusselt's* Formel für Wasserstoff zutrifft (*Steding*). Nach *Dommer* erhöhen Wassergehalte bis 10% die Entzündungsgeschwindigkeit des Kohlenoxyds, ebenso steigt diese im Unterdruck bis 300 mm und fällt bei niedrigeren Drücken (*Anwandter*). Durch Wärmeeinstrahlung wird nur beim Wasserstoff die Entzündungsgeschwindigkeit gesteigert, bei anderen Gasen nicht; inerte Gase verringern sie und zwar Kohlensäure stärker als Stickstoff.

Schliesslich wäre noch auf die Explosion (Verbrennung in abgeschlossenen Räumen) kurz einzugehen. Die *Explosionsgeschwindigkeit* übertrifft infolge der Drucksteigerung die *Verbrennungsgeschwindigkeit* und beträgt z.B. für Knallgas rd. 2 800 m/sec. Explosionen sind nur in bestimmten Mischungsverhältnissen mit Luft möglich. Man unterscheidet *untere* und *obere* Explosionsgrenze; die erstere bezieht sich auf die geringste Gasmenge in Vol–%, die im Gemisch mit Sauerstoff oder Luft zur Entzündbarkeit ausreicht, die andere auf die höchste Gasmenge, bei der aus Luftmangel die Entzündbarkeit gerade wieder aufhört. Die Grenzen sind nach *Eitner*[18]):

[12] *Ubbelohde* und *de Castro*, Diplomarbeit Karlsruhe 1909.
[13] *Hofsäss*, Gasjournal 1913.
[14] *Dommer*, Gasjournal 1914.
[15] *Koellicker*, Gasjournal 1915.
[16] *Anwandter*, Gasjournal 1916.
[17] *Steding*, Dissertation Giessen 1927.
[18] *Eitner*, Gasjournal 1902.

	Explosionsgrenzen untere %	obere %
H_2	9,45	66,4
CO	16,5	74,95
CH_4	6,1	12,8
C_2H_4	4.1	52,3
C_2H_2	3,35	14,6
C_6H_6	2,65	6,5

Später sind sie von *Terres* und *Plenz*[19]) und neuerdings sehr eingehend und unter verschiedenen Bedingungen von *Berl* und *Fischer*[20]) untersucht und bestimmt worden. Die neuesten Arbeiten darüber hat *Steding* insbesondere mit Rücksicht auf den Einfluss inerter Gase und Wassergas ausgeführt. Er arbeitete mit einem Steinkohlengas von 5 860 kcal und stellte fest, dass inerte Gase den Explosionsbereich ihrer Menge entsprechend einengen. Solange die Menge derselben 29% nicht überstieg, lag die untere Grenze bei Kohlensäure tiefer als bei Stickstoff, während die obere Grenze bei Kohlensäure stets tiefer lag. Gemische mit 71,4% CO_2 waren nicht mehr zur Explosion zu bringen, bei Gemischen mit 82% N_2 fielen untere und obere Grenze zusammen. Die Ursache der Verschiedenheit ist in dem Unterschied der spezifischen Wärmen zu suchen. Durch Zusatz von Wassergas wurde der Explosionsbereich bedeutend erweitert.

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THE PROPERTIES OF GASES DEFINING THEIR COMBUSTION

(English version—abridged)

While combustion broadly means the combination of any material with oxygen, only such combination with materials containing carbon and hydrogen comes into consideration in actual practice. Combustion can take place under three distinct conditions :

(1) *Theoretical combustion* in which the combustion products contain nothing but CO_2, H_2O and nitrogen.

(2) *Incomplete combustion* in which, in addition to the above, the combustion products will also contain an excess of the combustible gas.

[19] *Terres* u. *Plenz*, Gasjournal 1914.

[20] *Berl* u. *Fischer*, Z.f.Elektrochemie *30*, 1924.

(3) *Combustion carried out with excess air*, when the products will contain an excess of free oxygen.

The properties of gases upon which their combustion is dependent are the following:

Calorific value.
Air requirements.
Combustion and volume of combustion products.
Flame temperature.
Speed of combustion.
Ignition temperature.
Speed of ignition.
Explosive limits.
Speed of explosion.

In practice gas quantities are usually given by volumes and only rarely expressed by weight. Owing to the great fluctuations in volume associated with varying temperature and pressure conditions, it becomes necessary to reduce measured gas volumes to a set of standard conditions. The conditions forming the basis for gas measurement were in Germany previously 0°C and a pressure of 760 mm. of mercury, but in order to bring these conditions into line with actual practice a temperature of 15°C and a pressure of 760 mm. has now become usual. The basis for the correction of gas volumes in general are formed by the law of Avogadro (1811) and the rules of Gay-Lussac, Charles (1802), Boyle-Mariotte (1662) and Dalton (1807). The volumetric conversion of gas volume is carried out according to the following formula :—

$$V_{Pn,\ tn,\ \text{moist}} = V_{Pt,\ \text{moist}} \frac{\overbrace{B + p}^{P} - w_t}{P_n - w_{tn}} \quad \frac{273 + t_n}{273 + t}$$

in which B equals the barometric pressure, p equals the gas pressure over and above atmosphere, and w_t and w_{tn} equal the partial pressure of the water vapour at the temperatures t and t_n respectively.

For the conditions of temperature and pressure referred to above, the formulae take the following forms:

$$V_{760/0°,\ \text{dry}} = V_{Pt,\text{moist}} \overbrace{\frac{B + p - w_t}{273 + t} \times 0{\cdot}3592}^{=A}$$

$$\text{and } V_{760/15°,\ \text{moist}} = V_{Pt,\text{moist}} \underbrace{\frac{B + p - w_t}{273 + t} \times 0{\cdot}3854}_{=A'}$$

Junker's and Ludwig's tables serve for the determination of A. and Geipert's tables for the determination of A'.

The relationship between the two equations is as follows:

$$V_{760/0°,\ \text{dry}} : V_{760/15°\ \text{moist}} = 0{\cdot}3592 : 0{\cdot}3854$$
$$1 : 1{\cdot}073$$
$$0{\cdot}932 : 1$$

Calorific Value or heat of Combustion

By this it is understood the amount of heat which becomes available as a result of the combustion, the temperature of the resultant products being the

same as that of the combustible before combustion. Fuels containing a proportion of hydrogen have two distinct calorific values.

(1) The *gross* calorific value in which the heat of condensation of the water resulting from the combustion is taken into effect.

(2) The *net* calorific value in which it is assumed that the resultant water remains in vapour form. When the gross calorific value of a gas is known at 0°C and 760 mm. mercury, the net calorific value is obtained by deducting from this 485 calories per cu. metre of hydrogen. The latent heat of water by normal temperatures equals approximately 600 calories per cu. metre, and as 1 cu. metre of hydrogen yields 804 grams of water whether present as free hydrogen or in chemical combination, a deduction of 485 calories must be made.

The following table indicates the gross and net calorific values for some gases :

	Gross C.V. in calories per cu. metre (0°C. 760 mm. dry)	Net C.V. in calories per cu. metre (0°C. 760 mm. dry)
H_2	3,055	2,670
CO	3,035	3,035
CH_4	9,530	8,560
C_2H_6	16,550	15,095
C_3H_8	23,500	21,560
C_2H_4	15,380	14,410
C_2H_2	13,900	13,415
C_6H_6 (vapour) ...	34,865	33,410

The difference between the gross and net calorific values for coal gas amounts to just over 10 per cent. of the gross value, and by utilising this method of calculation it is possible to estimate the net calorific value of a gas when its gross calorific value is known.

In practice only combustion in air comes into consideration. As air is an unvarying mixture of 21 volumes of oxygen and 79 volumes of nitrogen, it becomes easy to arrive at the necessary volume of combustion air. 476 cu. metres of air contain one cu. metre of oxygen. In ordinary practice combustion is always associated with an excess of combustion air. The air requirements are easily ascertained from the combustion equations. For each carbon atom there is required for theoretical combustion 4.76 cu. metres of air per cu. metre of combustible gas and 2·38 cu. metres for each molecule of H_2. From these figures 4·76 cu. metres must be subtracted for each molecule O_2 present.

The table below indicates the air requirements per cu. metres for some of the most important gases.

	Air requirements per cu. metre of gas.
H_2	2·38
CO	2·38
CH_4	9·52
C_2H_6	16·66
C_3H_8	23·80
C_2H_4	14·28
C_2H_2	11·90
C_6H_6 (vapour)	35·70

The air requirement of a mixed gas is the sum of the air requirements of the component parts.

The composition and volumes of the products of combustion vary with the composition of the combustible. Pure carbon gives by combustion with the

theoretical amount of dry air a resultant product consisting of 21 per cent. CO_2 and 79 per cent. nitrogen. With the exception of CO all gaseous fuels give combustion products containing less than 21 per cent. CO_2. If pure CO is burnt with the theoretical amount of air the resultant combustion products will contain 34 per cent. CO_2 and 65·3 per cent. nitrogen. The usual methods of gas analysis (Orsat, etc.) always indicate the dry composition of the combustion products. The volume and composition of the combustion products from the most important gaseous fuels are given below :—

	Volume of combustion products in cu. metres per cu. metre of gas.		Composition of combustion products.	
	Moist	Dry	Moist	Dry
H_2	1·88 N_2 1 H_2O 2·88	1·88 N_2	65·3% N_2 34·7% H_2O	100% N_2
CO	—	1·88 N_2 1 CO_2 2·88	—	65·3% N_2 34·7% CO_2
CH_4	7·52 N_2 1 CO_2 2 H_2O 10·52	7·52 N_2 1 CO_2 8·52	71·5% N_2 9·5% CO_2 19·0% H_2O	88·3% N_2 11·7% CO_2
C_2H_6	13·16 N_2 2 CO_2 3 H_2O 18·16	13·16 N_2 2 CO_2 15·16	72·5% N_2 11·0% CO_2 16·5% H_2O	86·8% N_2 13·2% CO_2
C_3H_8	18·8 N_2 3 CO_2 4 H_2O 25·8	18·8 N_2 3 CO_2 21·8	72·9% N_2 11·6% CO_2 15·5% H_2O	86·2% N_2 13·8% CO_2
C_2H_4	11·28 N_2 2 CO_2 2 H_2O 15·28	11·28 N_2 2 CO_2 13·28	73·8% N_2 13·1% CO_2 13·1% H_2O	84·9% N_2 15·1% CO_2
C_2H_2	9·4 N_2 2 CO_2 1 H_2O 12·4	9·4 N_2 2 CO_2 11·4	75·8% N_2 16·1% CO_2 8·1% H_2O	82·5% N_2 17·5% CO_2
C_6H_6 (Vapour)	28·95 N_2 6 CO_2 3 H_2O 37·95	28·95 N_2 6 CO_2 34·95	76·3% N_2 15·8% CO_2 7·9% H_2O	82·8% N_2 17·2% CO_2

Composition and volume of the products of combustion of a mixed gas is the sum of the volumes of the combustion products of the component part of the gas. The maximum CO_2 content of gaseous fuels used in practice varies with the fuel but is always below 21 per cent. For town gas it is approximately 12 per cent., and for producer gas about 20 per cent. The Bunte's diagram or tables based upon this serves for the approximate calculation of the composition of combustion products from their CO_2 content.

Flame Temperature.

The flame temperature indicates the temperature of the products of combustion presupposing that all the heat generated is taken up by these without any losses on account of radiation or convection. (Adiabatic combustion.) The theoretical flame temperature is calculated by means of the following formula:—

$$t = \frac{H_u + Q}{AC_A + BC_B + CC_C}$$

in which H_u indicates the net calorific value.
Q the sensible heat of gas and air.

$$\left.\begin{array}{l} A \text{ m}^3\ O_2 + N_2 \\ B \text{ m}^3\ CO_2 \\ C \text{ m}^3\ H_2O\text{-vapour} \end{array}\right\} \text{Resulting from combustion per cu. metre of fuel gas.}$$

C_A, C_B, C_C mean specific heats of the component parts of combustion products at constant pressure at the flame temperature t.

As the specific heat varies with the temperature it becomes necessary to assume a flame temperature and to use the specific heat corresponding to this in the above equation. The correct specific heat for the temperature calculated is then substituted in the equation, and this process is repeated until sufficient accuracy is obtained.

According to Neumann [B. Neumann, Journal für Gasbeleuchtung 62, 606 (1919)] the mean specific heats between 0°C and t°C are as follows :—

	CO_2 SO_2	H_2O-vapour	N_2, O_2, CO, air
0°C	0·397 Cals/m³	0·372 Cals/m³	0·312 Cals/m³
500	0·467	0·380	0·322
1,000	0·511	0·398	0·332
1,500	0·536	0·424	0·342
2,000	0·556	0·465	0·352
2,500	0·570	0·516	0·362
3,000	0·581	0·573	0·372

Schack (A. Schack, Mitteilungen der Wärmestelle Düsseldorf des Vereins deutscher Eisenhüttenleute No. 87) suggests the following formula for the calculation of flame temperatures:

Between 800 and 1,800°C—

$$t = \frac{H_u + Q + 32A + 80B + 75C}{0{\cdot}364A + 0{\cdot}591B + 0{\cdot}477C};$$

Between 1,700° and 2,800°C—

$$t = \frac{H_u + Q + 93{\cdot}5A + 128B + 448C}{0{\cdot}400A + 0{\cdot}621B + 0{\cdot}695C}.$$

See preceding formula for reference letters.

The results obtained agree to within plus or minus ½ per cent. with the results obtained by the usual "trial and error" method.

The following table indicates the flame temperatures for certain gases obtained by the above formula:—

		1,000 · (Vol. of combustion products : H_u)
H_2	2,205°C	1·08
CO	2,430	0·95
CH_4	2,050	1·23
C_2H_6	2,085	1·20
C_3H_8	2,095	1·20
C_2H_4	2,325	1·06
C_2H_2	2,635	0·92
C_6H_6	2,200	1·14

As indicated by the above table, the flame temperature of any gas is not directly proportional to its calorific value, but varies with the quotient:

$$\frac{\text{Vol. of combustion products}}{\text{Calorific value}}$$

The flame temperature of a mixture is not the sum of flame temperatures of the components. All flame temperature calculations are based upon the assumption that combustion takes place without dissociation. Both CO_2 and hydrogen become dissociated to some extent at temperatures above 1,700°C and the corresponding flame temperatures are therefore affected.

Nernst and his pupils (W. Nernst, Theoretische Chemie, Edition 8 to 10, page 763, Stuttgart 1921) have worked out the dissociation values of CO_2 and H_2O, and Schack (A. Schack, Mitteilungen der Wärmestelle Düsseldorf des Vereins deutscher Eisenhüttenleute No. 79) has worked out a formula for flame temperature calculations taking dissociation into consideration. Comparative flame temperatures, with or without dissociation for hydrogen and CO are as follows :—

	Without dissociation	With dissociation
H_2	2,205°C	2,145°C
CO	2,430°C	2,095°C

These results are confirmed by practice.

Speed of Combustion.

Speed of combustion depends upon flame temperature, conductivity, ignition temperature and specific heat. It is greatest with hydrogen equalling 20 metres per second when this is burnt with oxygen, and lowest with CO, equalling 2 metres per second when this is burnt under similar conditions. Speed of combustion usually reaches the maximum under theoretical combustion conditions, except with hydrogen, where a small excess of this is advantageous. Speed of combustion falls when air is substituted for oxygen as the combustion medium, and equals under these conditions 2 metres per second for hydrogen and 0·3 metres per second for CO. [Hofsäss, Journal für Gasbeleuchtung 62, 545 (1919).]

Ignition Temperature.

The ignition temperature is that at which a gas ignites in oxygen or air

without free flame. [Dixon and Coward, Journal of the Chemical Society 95, 514 (1909).] Dixon and Coward found the following mean values :—

	In oxygen	In air
H_2	585°C	585°C
CO	650	651
CH_4	556—700	650—750
C_2H_6	520—630	520—630
C_3H_8	490—570	—
C_2H_4	510	540
C_2H_2	428 (?)	429

Speed of Ignition.

By this it is understood the rate of propagation of ignition of gas. It is dependent upon the calorific value, conductivity, specific heat, initial temperature and ignition temperature of the gases.

Nusselt (Z.d.V.D.I. (1915)) gives the following formula for the determination:

$$W = \sqrt{\frac{C_1 \cdot \gamma \cdot p_0 \cdot T_0^2 \, (T_v - T_c) \, G_2^\circ \, O_2^\circ}{103{\cdot}7 \cdot R^2 \cdot C_p \, (T_c - T_0)}}$$

in which—

W = rate of ignition in metres per second.
γ = mean conductivity of heat of the gas mixture.
p_0 = pressure.
T_0 = initial temperature of gas.
T_c = ignition temperature.
G_2° = volume of gas before combustion.
T_v = flame temperature.
O_2° = volume of oxygen before combustion.
C_p = means of specific heat per unit volume of gas mixture between T_e and T_v at 15°C. and the pressure of one atmosphere.
R = Gas constant.
C_1 = a constant to be determined by trial.

Experimental work on the rate of ignition of gases have been carried out by the following investigators :—

Ubbelohde und de Castro, Diplomarbeit Karlsruhe 1909.
Hofsäss, Gasjournal 1913.
Dommer, Gasjournal 1914.
Koellicker, Gasjournal 1915.
Anwandter, Gasjournal 1916.
Steding, Dissertation Giessen 1927.

Steding states that Nusselt's formula is correct for hydrogen. According to Dommer the speed of ignition is increased by a water content up to 10 per cent. for CO, and it is also increased by a decrease in pressure up to 300 mm. and falls by lower pressures (Anwandter).

The speed of ignition of hydrogen is increased by radiant heat ; other gases remain unaffected. It is lowered by inerts ; by CO_2 more than by nitrogen.

Rate of Ignition.

Explosions are only possible between lower and upper limits, the lower limit indicating the minimum volume of gas expressed in percentage, and the latter the maximum volume which is capable of ignition when mixed with O_2 or air. Eitner (Eitner, Gasjournal 1902) gives the following explosive limits :—

	Lower %	Upper %
H_2	9·45	66·4
CO	16·5	74·95
CH_4	6·1	12·8
C_2H_4	4·1	52·3
C_2H_2	3·35	14·6
C_6H_6	2·65	6·5

Terres and Plenz (Gasjournal 1914), Berl and Fischer (Z.f.Elektrochemie 30, 1924) have also carried out work in this connection. Steding has carried out recent research work in order to establish the effect of inerts. Working on coal gas of a calorific value of 5,860 calories he ascertained that the presence of inerts lowered the explosive properties in proportion to their percentages. With percentages not exceeding 29 per cent. it was found that the lower limit was depressed by means of addition of CO_2 to a greater extent than if nitrogen were used, whereas at the upper limit this was always lower for CO_2. Mixtures containing 71·4 per cent. CO_2 could not be made to explode, and by admixture of 82 per cent. nitrogen upper and lower limits coincide. The reason is to be found in the difference in specific heat. The explosive range was considerably extended by the addition of water gas.

DIE GEWINNUNG VON GAS UND SONSTIGEN ERZEUGNISSEN IN DEN WIENER STÄDTISCHEN GASWERKEN

(THE PRODUCTION OF GAS AND THE RECOVERY OF OTHER PRODUCTS BY CARBONISATION IN THE VIENNA MUNICIPAL GASWORKS)

AUSTRIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

F. MENZEL

Paper No. H5

CONTENTS

RÉSUMÉ

Die Gaswerke der Stadt Wien erzeugen ein Mischgas von 4 250 WE oberen Heizwert (0°C, 760 mm B.St.) aus Steinkohle und Koks. Diese Rohstoffe und die chemischen Prozesse, denen sie unterzogen werden, sind fast allen Gaswerken gemeinsam. Auch die Gaswerksanlagen selbst sind im Wesentlichen von einander nicht sehr verschieden. Es wäre daher sehr überflüssig, über die Wiener Gaswerke an dieser Stelle—wenn auch nur ganz kurz—zu berichten, wenn sie nicht im Vergleiche mit anderen Gaswerken einiges Bemerkenswertes aufzuweisen hätten.

Die Gasversorgung der Stadt Wien und einiger Ortschaften der Umgebung erfolgt durch zwei städtische Werke, SIMMERING und LEOPOLDAU, die zusammen eine Leistungsfähigkeit von 1 500 000 m^3/24 Std. besitzen. Sie sind an die Stelle von 8 Gaswerken getreten, die teils bis November 1899, teils bis Ende 1911 von Gasgesellschaften betrieben wurden.

Das Werk Simmering kam am 1. November 1899, das Gaswerk Leopoldau am 1. Jänner 1912 in Betrieb.

Das Werk Simmering besass bei seiner Inbetriebsetzung 180 Coze-Oefen zu je 9 Retorten, eine Ofenbauart, die damals noch wenig

verbreitet war; die Tagesleistung dieser Oefen betrug 430 000 m³. Als eine Leistungserhöhung des Werkes um 70 000 m³/24 Std. notwendig wurde, sah die Leitung der Wiener Gaswerke von der Herstellung weiterer Kleinofeneinheiten von vorneherein ab. Es wurden Angebote für Ofeneinheiten grosser Leistung, G r o s s r a u m ö f e n, aber beliebiger Bauart eingefordert. Unter den eingelangten Angeboten befand sich auch eines der Firma H. KOPPERS, Essen/Ruhr, auf Schrägkammeröfen. Die Kammern hatten einen Fassungsraum für je 7 000–7 500 kg Kohle (gegenüber den Coze-Retorten von 180 kg), so dass die Tagesleistung einer Kammer bei 24 stündiger Garungszeit rd. 2 400 m³ Gas war. Für die Beheizung der Kammern hatte die Firma in die Oefen eingebaute Generatoren vorgesehen. Eine Anlage derselben Ausführung erbaute die Firma damals im Gaswerke BOCHUM (Westfalen); diese Anlage kam im August 1908 in Betrieb.

Diese Oefen waren hinsichtlich gewährleisteter Gasausbeute, Unterfeuerungsverbrauch u.s.w. den Oefen anderer Angebotsteller ebenbürtig, die Baukosten waren aber bedeutend geringer als die in den anderen Angeboten geforderten. Die Wiener städtischen Gaswerke hatten jedoch Bedenken gegen die Beheizung der Kammern mit angebauten Generatoren, weil die Kammerkonstruktion aus der Kokereiindustrie übernommen war, die bekanntlich ihre Oefen mit dem bei der Verkokung entstehenden, von Flugstaub freien Gase beheizt. Da die üblichen Generatoren ein Gas mit grossem Flugstaubgehalte liefern, waren Verschmutzungen und Verschmelzungen der Düsen und Heizzüge der Kammerwände und dadurch Störungen, wenn nicht sogar ein baldiges gänzliches Versagen der Ofenanlage zu befürchten. Es wurde daher von den Wiener Gaswerken die Beheizung durch a b s e i t s v o n d e r O f e n a n l a g e a u f g e s t e l l t e G e n e r a t o r e n m i t F l u g s t a u b a b - s c h e i d e r n gefordert. Die Firma teilte die Bedenken nicht, musste aber nach längerem Widerstreben der Forderung der Gaswerke entsprechen. Die Kammerofenanlage erhielt 3 Duff-Generatoren (nach Ausbau der Anlage 5) mit je einem Staubabscheider.

Das Gaswerk Wien-Simmering war so d a s e r s t e G a s w e r k, in dem Gaserzeugungsöfen durch eine Z e n t r a l - G e n e r a t o - r e n a n l a g e beheizt wurden.

Der Betrieb der Anlage zeigte, dass die angewendete Ausführungsart der Staubabscheider zwar ihren Zweck nicht vollständig erfüllte, dass aber die Zentral-Generatorenanlage auch noch andere grosse Vorzüge, von denen später gesprochen werden wird, gegenüber der bisherigen

Ofenbeheizung besitzt. Als daher im Jahre 1909 der Firma KOPPERS die Ausführung einer Horizontal-Kammerofen-Anlage, wie sie die Kokereien verwenden, im Werke Simmering übertragen wurde, stand von vorneherein fest, dass für die Beheizung der Kammern nur Zentral-Generatoren in Betracht kommen können. An Stelle der Duff-Generatoren wurden selbstschlackende Drehrost-Generatoren, Bauart KERPELY, und statt der Trocken-Staubabscheider eine nasse Staubabscheidung gewählt. Die Kerpely-Generatoren sollten nach Absicht der Firma die üblichen Wasserkühlmäntel erhalten. Da die städtischen Gaswerke aber die Einrechnung des Kraftbedarfes der Nassreinigung und der Förderung des Generatorgases zu den Oefen in den sehr niedrigen, durch ein ganzes Jahr hindurch nachzuweisenden und unter hohes Strafgeld gestellten Unterfeuerungsverbrauch der Kammeröfen forderten, entschloss sich die Firma, den Kühlmantel als Dampfkessel auszubilden, um den auf diese Weise ohne Brennstoffaufwand anfallenden Dampf zum Maschinenbetrieb der Generatorgaswaschung und Generatorgasförderung zu verwenden.

Obwohl eine derartige Anlage noch nirgends ausgeführt war und diese Lösung ein ernstes Wagnis bedeutete, entschlossen sich die städtischen Gaswerke nach gründlicher Prüfung dennoch zu ihrer Durchführung. Sie brachte den angestrebten betriebstechnischen und wirtschaftlichen Erfolg.

Auch der Uebergang von den u.a. schwierig zu beheizenden grossen Schrägkammern auf grosse Horizontalkammern erwies sich technisch und wirtschaftlich als bedeutender Fortschritt.

Damit war auch die wichtige Wahl des Ofensystems für das neu zu erbauende Gaswerk Wien-LEOPOLDAU entschieden.

Dieses Werk, in den Jahren 1910 und 1911 infolge Vergrösserung des Gasversorgungsgebietes errichtet, erhielt als erstes Gaswerk ausschliesslich Horizontal-Kammeröfen. Die Anlage bestand aus 72 Kammern für je 11 Tonnen Kohlenladung und ist seither auf 141 Kammern ausgebaut worden.

Da die im Werke SIMMERING von der Firma KOPPERS aufgestellten Dampfkessel-Generatoren im Laufe des Betriebes einige konstruktive Mängel zeigten, wurden beim weiteren Ausbau der Kammerofen-Anlage dieses Werkes und von vorneherein im Werke LEOPOLDAU Dampfkessel-Generatoren werkseigener Konstruktion (Bauart MARISCHKA) für 6 atü Spannung aufgestellt. Diese Ausführung hat sich vorzüglich bewährt. Es stehen in den beiden Werken 34 dieser Generatoren, hievon mehr als die Hälfte seit nahezu 20 Jahren, in Verwendung.

Die Zentralgeneratorenanlagen der Wiener Gaswerke besitzen folgende Vorzüge: Sie liefern den Oefen ein praktisch staubfreies und dadurch die Oefen schonendes Generatorgas von stets gleichmässiger Beschaffenheit. Sie können mit Koks jeder Art, auch mit sehr aschereichem, betrieben werden. Die Generatorgaserzeugung ist in weiten Grenzen veränderlich. Die Zufuhr des Heizgases für die Oefen ist dem jeweiligen Bedarfe entsprechend genau regelbar. Die Generatoren erzeugen den zu ihrem Betrieb erforderlichen Unterdampf und den zur Generatorgasreinigung und zur Gasförderung notwendigen Kraftdampf ohne jeden Brennstoffaufwand und liefern noch für andere Zwecke verwendbaren Ueberschussdampf. Die Instandhaltungs- und Betriebskosten der Anlage sind gering. Die anfallende Schlacke wird selbsttätig ausgetragen und enthält nur einen ganz geringen Prozentsatz an Verbrennlichem.

Alle diese Eigenschaften machen die Beheizung der Oefen mit Zentral-Generatoren denjenigen mit angebauten oder eingebauten Generatoren technisch und wirtschaftlich überlegen. Es hat merkwürdigerweise verhältnismässig lange Zeit gebraucht, bis diese bedeutenden Vorzüge in Fachkreisen erkannt wurden. Heute ist diese, einen zweifellosen Fortschritt in der Gaserzeugungstechnik darstellende Beheizungsart bei Gaserzeugungsöfen verschiedener Bauart schon stark verbreitet. Auch in der Ferngasversorgung Deutschlands wird an eine Ausrüstung der neuen Kokereien mit Zentral-Generatorenanlagen gedacht.

In den letzten Jahren wurden auch 80 Coze-Oefen des Werkes Simmering für Regenerativbeheizung umgebaut und an die Zentral-Generatorenanlage angeschlossen.

Dass in der Ofenfrage die Wiener städtischen Gaswerke schon vor nahezu 2 Jahrzehnten von den in Gaswerken herkömmlichen Ofensystemen abgewichen sind, ist schon erwähnt worden. Die Horizontal-Kammeröfen der Kokereien waren aber nicht ohne weiteres für die Gaswerke verwendbar. Die Kokereien beheizen ihre Oefen unter Vorwärmung der Verbrennungsluft in Regeneratoren mit dem bei der Kokserzeugung gewonnenen heizkräftigen Gase, während die Wiener Oefen mit dem heizschwachen Generatorgase zu beheizen waren. Der der Firma H. KOPPERS auferlegte geringe Unterfeuerungsverbrauch zwang sie, nicht nur die Verbrennungsluft sondern auch das Generatorgas durch Ausnützung der Wärme der Verbrennungsgase vorzuwärmen. Dies geschah mit dem Erfolg, dass die durch den Schornstein abziehenden Abgase nur mehr die für den Schornsteinzug notwendige Temperatur von rd. 250°C besitzen, während bei anderen Gaswerksöfen die Abgasetemperaturen weit höher sind und nur

durch Aufstellung von Abhitze-Dampfkesseln verwertet werden können. Eine weitere Neuerung wurde im Jahre 1913 im Werk LEOPOLDAU durch Erbauung einer Horizontalkammerofenanlage, bestehend aus 21 Kammern, geschaffen, die sowohl mit Generatorgas als auch mit dem erzeugten Leuchtgas beheizt werden kann. Diese Oefen, von der Firma KOPPERS Verbundöfen genannt, geben die Möglichkeit, bei günstigen Erlösen aus Koks, Teer usw. die Erzeugung an diesen Waren bis zu einer bestimmten Grenze zu erhöhen, ohne mit der Gaserzeugung über den jeweilig notwendigen Gasbedarf hinausgehen zu müssen. Der Fall, in dem die Beheizung mit Leuchtgas wirtschaftliche Vorteile bringt, ist jeweils leicht zu errechnen. Er ist in Wien schon wiederholt eingetreten. Auch die Verbundöfen haben seither in Gaswerken Eingang gefunden und sie sollen auch in der geplanten Ferngasversorgung der rheinisch-westfälischen Zechen eine bedeutende Rolle spielen.

Die zur Gaserzeugung notwendige Kohle muss Oesterreich ausschliesslich aus dem Auslande beziehen. Um diese Einfuhr auf das Unerlässliche zu beschränken, erzeugen die Wiener städtischen Gaswerke ein Mischgas aus Kohlengas und Wassergas, das den deutschen Normen entspricht. Jedes der beiden Werke besitzt daher eine Wassergasanlage. Das Werk Simmering hat eine aus 5 Doppelgeneratoren bestehende Anlage, System HUMPHREYS & GLASGOW, mit Oelkarburation und einen neuen selbstschlackenden Drehrostgenerator mit Dampfkesselmantel.

Im Werke Leopoldau ist eine Wassergasanlage, bestehend vorläufig aus drei selbstschlackenden Drehrost-Generatoren mit Abhitzekesseln, vorhanden. Der Simmeringer Drehrost-Generator und die Leopoldauer Anlage erzeugen den zur Wassergasherstellung erforderlichen Betriebsdampf durch Ausnützung des Wärmeinhaltes der Blasegase selbst. Eine Karburation des Wassergases findet nur ausnahmsweise statt.

Im Werke Simmering ist seit einigen Monaten auch eine Anlage für restlose Vergasung von Steinkohle (System Strache) im Betrieb. Sie erzeugt 72 000 m³ Gas/24 Std. mit einem oberen Heizwerte von 3 200 bis 3 300 WE, 0°C, 760 mm B. Std. 160 m³ Gasausbeute/100 kg und ist derzeit die grösste derartige Gaswerksanlage.

Die grosse Bedeutung, die die Koksbeschaffenheit für den Koksabsatz hat, war für die Wiener städtischen Gaswerke bestimmend, der Aufbereitung der Kohle eine besondere Aufmerksamkeit zuzuwenden. Die Tatsache einer bedeutenden Verbesserung der Koksbeschaffenheit, die durch Mahlung

gegenüber dem in Gaswerken üblichen blossen Brechen der Kohle erzielt wird, führte im Jahre 1922 zu dem Bau einer Kohlenmahlanlage für die Kammeröfen des Werkes Simmering. Sie war die erste in einem Gaswerke aufgestellte Anlage. Der nach Mahlung der Kohle erzeugte Koks ist von so guter Beschaffenheit, dass das grösste österreichische Eisenwerk mit ihm durch mehrere Monate seine Hochöfen betreiben konnte. In der Folge erhielt auch das Werk Leopoldau für seine Oefen eine Anlage, die nicht nur zur Mahlung sondern auch zur Mischung der verschiedenen Kohlensorten dient.

Diese Kohlenaufbereitungsanlagen in Verbindung mit den einen festen Koks liefernden Horizontal-Kammeröfen und neuzeitlichen Kokslöschanlagen, die einen geringen Löschwasser-Gehalt des Kokses und dadurch dessen reine Sortierung ermöglichen, haben bewirkt, dass der für Heizzwecke nach Oesterreich eingeführte ausländische Hüttenkoks immer mehr zurückgedrängt wird. Die Wiener städtischen Gaswerke sind auch auf Grund eingehender Versuche darangegangen, durch entsprechende Auswahl und Mischung von Kohlen Giessereikoks, der bisher ausschliesslich aus dem Auslande bezogen werden musste, zu erzeugen.

Fin anderes wichtiges Gaswerkserzeugnis, den Teer, verarbeitet das städtische Unternehmen nicht selbst. Es besitzt aber die Aktienmehrheit der grössten Teerdestillation Oesterreichs, so dass es auch an der Verarbeitung und Verwertung seines Teeres massgebend beteiligt ist.

Jedes der beiden Werke hat eine Fabriksanlage zur Weiterverarbeitung des erzeugten Ammoniaks auf Ammonsulfat, Salmiakgeist u.a.m.

Ein besonderer Betriebszweig der Wiener Gaswerke ist seit dem Kriege die Gewinnung von Benzolkohlenwasserstoffen aus dem Gase. Auf dem europäischen Festlande geschieht dies nur in verhältnismässig wenigen Gaswerken, in keinem aber werden Fertigerzeugnisse in solcher Mannigfaltigkeit wie in Wien hergestellt. Beide Gaswerke besitzen je eine Anlage zur Auswaschung der Benzolkohlenwasserstoffe. Die Weiterverarbeitung zu Fertigerzeugnissen geschieht in der Benzolfabrik des Werkes Leopoldau. In ihr werden Motorbenzol, 90er Benzol, Reinbenzol, Toluol, Xylol und Solventnaphta erzeugt. Der Fabrik sind auch eine Waschölregenerieranlage und eine Anlage zur Verarbeitung der ausgebrauchten Schwefelsäure auf Eisenvitriol und Zinksulfat angegliedert. Das Motorbenzol wird an die städtischen und an private Kraftwagenbetriebe wie auch an die Wien berührenden Flugverkehrsgesellschaften

geliefert. Das Toluol geht in die Saccharinfabriken, das Reinbenzol hauptsächlich an ausländische Farbstoff-Fabriken.

Die Wärmewirtschaft betreffend, wurde schon früher auf die vorzügliche Ausnützung des zur Unterfeuerung der Gaserzeugung verwendeten Kokses in den Zentral-Generatoren und auf den sehr geringen Unterfeuerungsverbrauch der Horizontalkammeröfen hingewiesen. Die Kraftdampferzeugung in den Werken erfolgt zum Teile durch Verfeuerung des minderwertigen und schwer verkäuflichen Staubkokses auf Rosten, die ausschliesslich diesen schwer entzündbaren Heizstoff mit gutem Wirkungsgrade verbrennen.

Für die Beheizung sämtlicher Werksräume, der Gasbehälter und zur Bereitung des Warmwassers für die Wasch- und Badeanlagen besitzt jedes der beiden Werke eine ausserordentlich wirtschaftlich arbeitende Warmwasser-Zentrale, die durch Ausnützung des Ueberschussdampfes der Zentralgeneratoren und des Auspuffdampfes von Maschinen die nötigen Warmwassermengen herstellen und verteilen. Auch die Ammoniakfabriken erhalten den grössten Teil ihres Betriebsdampfes kostenlos von den Zentralgeneratoren geliefert.

Als bemerkenswert sei noch erwähnt, dass die Wiener städtischen Gaswerke als erste am europäischen Festlande seit dem Jahre 1910 den Ausbau ihrer Schwefelentfernungsanlagen durch im Freien liegende Reinigerkasten, die in den letzten Jahren aus Eisenbeton hergestellt wurden, durchgeführt haben. Diese Ausführungsart verbilligt durch den Wegfall der Gebäude nicht nur bedeutend die Anlagekosten, sondern vermindert auch in hohem Grade die Gefahr von Zündschlägen und Bränden.

Es darf daher wohl gesagt werden, dass in Wien die Gewinnung von Gas und sonstigen Erzeugnissen in ihrer Entwicklung und in ihrem heutigen Stande im Vergleiche mit anderen Gaswerken in wichtigen Belangen eigene Wege gegangen ist.

RÉSUMÉ

The city of Vienna owns two gasworks, with a total capacity of 1,500,000 cu. m. (53,000,000 cu. ft.) per 24 hours. From coal and coke, a mixed gas of 4,250 heat units (446 B.Th.U. per cu. ft.) is manufactured. The Simmering works, which started gas making in 1899, was at first equipped with inclined retorts on the Coze system. In 1908 it was extended by the installation of an inclined chamber oven plant of the Koppers type, heated by Duff producers situat d away from the ovens. The Simmering gasworks was the first in which central producers were used. In 1909 the works was extended by the

erection of a horizontal chamber oven plant on the Koppers system, heated by automatic slag-removing rotary grate Kerpeley producers, with producer gas purification by the wet method. Later on these producers were equipped with a steam jacket of our own (Marischka) construction. Using small lump coke, even with a high ash content, the producers make a gas free of dust, and ensure uniform heating of the ovens, which contributes largely to their preservation. In addition, the producers make more steam than they themselves require.

The Leopoldau works, started in 1912, was the first gasworks where horizontal chamber ovens with steam raising producers, were exclusively installed. In 1913 the works was extended by an installation of combination coke ovens, which may be heated either by producer gas or coal gas.

The latest extension at Simmering gasworks comprises a plant for the complete gasification of coal on the Strache system, making gas of 3,200 heat units (342 B.Th.U. per cu. ft.). This is the largest plant yet built in a gasworks on this system.

In order to improve the quality of coke a coal disintegrator was erected in 1922 at Simmering gasworks. Soon afterwards the Leopoldau works was equipped with a plant for grinding and blending the coal. The coke is of a very good quality and is, therefore, displacing foreign metallurgical coke.

The tar extracted from the gas is worked up in the largest tar distillation plant in Austria, of which the Vienna Municipal Gasworks owns the majority of shares.

Sulphate of ammonia, ammonium chloride, and carbonate of ammonia, are recovered from the ammoniacal liquor.

Motor benzol, pure benzol, pure toluol, xylol and solvent naphtha, are manufactured in the benzol plant on the works.

The heat economy of both works is characterised by the low demand for fuel on the horizontal chamber ovens, by the excellent utilisation of the coke fuel in the central generators, by the manufacture of steam for power purposes from coke dust, by the operation of the ammonia plant and the benzol plant with excess steam, and by the utilisation of exhaust and excess steam for providing hot water for baths and washing, and for heating the gasholders and the rooms on the works. The heat economy may, therefore, be considered to be very good.

The Vienna Municipal gasworks since 1910 have erected their oxide purification plants in the open air with great success. For the past few years they have built the purifier boxes of ferro concrete.

DOMESTIC FUELS OTHER THAN ANTHRACITE

U.S. BUREAU OF MINES

Paper No. H6

CONTENTS

INTRODUCTION

In that part of the United States conveniently accessible to the mines of Eastern Pennsylvania, anthracite has long been the standard fuel for house-heating. Anthracite is admirably adapted for this purpose because it burns without smoke or soot, makes little dust, and produces a fire that can be regulated with a minimum of attention. There are, however, many localities in which anthracite is beyond the means of the average consumer, largely because of the cost of transportation from the mines. Indeed, over most of the country bituminous coal is the fuel more commonly used and as shown by the following table, the total quantity of bituminous coal used for house-heating equals or exceeds the consumption of anthracite. Over much of the country, therefore, the development of some fuel cleaner than the average raw bituminous coal is a problem of great importance.[1]

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[1] Unless otherwise specified all quantities in this paper are expressed in short or net tons of 2,000 pounds, in gallons of 231 cubic inches, and in barrels of 42 gallons each.

COMMERCIAL PRODUCTION OF ANTHRACITE AND TOTAL SUPPLIES OF OTHER FUELS USED FOR DOMESTIC PURPOSES IN THE UNITED STATES, 1924–1927.

(The figures for 1925 and 1926 were affected by the great strike of the anthracite miners which lasted from September 1, 1925, to February 18, 1926).

	1924	1925.	1926.	1927.
Solid fuels (net tons)				
Anthracite production:				
Shipments of domestic sizes	56,576,296	38,305,222	54,096,437	48,999,058
Shipments of buckwheat No. 1[1] ...	9,510,508	6,631,604	8,581,966	9,062,977
Shipments of smaller steam sizes ...	11,160,695	8,831,546	12,640,416	12,433,251
Local sales...	3,043,939	2,884,577	2,687,411	3,046,770
Total commercial production ...	80,291,438	56,652,949	78,006,230	73,542,056
Anthracite exported...	4,017,785	3,179,006	4,029,683	3,325,507
Anthracite imported, chiefly from United Kingdom	117,951	382,894	813,956	119,030
Fuel briquettes produced	580,470	839,370	995,332	970,468
Fuel briquettes imported	38	6,758	123,593	60,601
By-product coke sold for domestic use ...	2,812,771	4,085,068	5,056,568	4,702,529
Beehive coke sold for domestic use ...	139,886	392,698	386,045	75,219
Coke imported	82,833	201,579	284,548	168,859
Gas-house coke sold...	About 1,300,000 tons a year.			
Petroleum coke produced[2]	761,100	991,000	995,300	1,145,200
Bituminous coal for domestic use[3]... ...	From 56,000,000 to 77,000,000 tons a year.			
Oil (barrels)				
Oil used for heating houses[4]	2,800,000	5,000,000	8,800,000	11,000,000
Oil used for heating offices, hotels, apartments, schools, hospitals and buildings other than houses	No data	[5]12,100,000	14,266,000	14,800,000

[1]A considerable part of the buckwheat No. 1 is used for domestic purposes.
[2]How much of the petroleum coke produced was used for house fuel is not known. It is known that 314,000 tons in 1925, about 408,000 tons in 1926, and 450,000 tons in 1927 were used for refinery fuel.
[3]During the anthracite strike about 18,000,000 tons of bituminous coal, in addition to the normal consumption, was used to replace anthracite.
[4]Figures relate to heating seasons as follows: 2,800,000 barrels in season of 1923–24, 5,000,000 in season of 1924–25, 8,800,000 in season of 1925–26. The figure for 1927 represents the calendar year.
[5]Partly estimated.

PART I—PROCESSED COALS

F. G. TRYON

Fuel Briquettes

An early approach to the problem was the briquetting of anthracite culm or the screenings from low-volatile bituminous coal. But although the fuels used by the briquetting plants are "smokeless," the asphalt or coal-tar pitch commonly used as binder gives off an objectionable smoke.[2] By re-carbonizing the briquettes as they come from the presses, the smoke of the binder

[2] Three plants briquetting the carbon residue of oil gas use no binder.

can be expelled, but this more elaborate process adds to the cost of manufacture, and the extra expense further handicaps the product in competition with the cheap raw coals. Re-carbonising was practised by only four plants in 1927 and applied to but 11,483 tons of finished product. The great obstacle to the expansion of the briquetting industry in the United States has been the abundance of anthracite and low-volatile bituminous coal suitable for household use. In the past twenty years a total of forty-three briquetting plants have gone out of business, and the production of briquettes, though now increasing steadily, is still small. In 1927, nineteen plants produced 970,468 tons of briquettes. In certain localities, however, the briquetting industry is firmly established, particularly at the head of Lake Superior, where domestic anthracite is expensive because of the distance from the mines and where a supply of material suitable for briquetting is available at low cost through the breakage of coal shipped up the Great Lakes.

Low-Temperature Carbonisation

In the United States, as elsewhere, there has been active interest in the carbonisation of coal at low temperatures. Briquettes made from low-temperature char or semi-coke were sold by two plants in 1927, located at Fairmont[3] and Moundsville, West Virginia. Such a briquette, recarbonised to drive off smoke from the binder, is an excellent domestic fuel. Several other plants,[4] largely in the experimental stage, have from time to time made low-temperature coke, designed for domestic use. At a number of these plants the results have been so encouraging as to induce the owners to expand their capacity and to undertake the construction of new plants on a commercial scale. The quantities produced by low-temperature carbonisation, however, are still an insignificant element in the total supply of house fuel. It remains a question of wide interest how successfully low-temperature methods can

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[3] See Carnegie Institute of Technology, Proceedings of the International Conference on Bituminous Coal, 1926, particularly McIntire, Development in low-temperature distillation of coal at Fairmont, West Virginia.

[4] Carnegie Institute of Technology, work cited: Runge, The McEwen-Runge process for the low-temperature distillation of coal; Greene, The Greene-Laucks process; Piron and Crawford, The Piron coal distillation process; Darrah, The low-temperature distillation of coal in rotary retorts; Parker, The Bussey process of low-temperature distillation; Wisner, The missing link in low-temperature carbonisation.

complete with anthracite and high-temperature coke under present conditions and price levels in the United States.

GAS COKE

Carbonisation at high temperatures, on the other hand, is securely established as a source of domestic fuel in America, and the quantity of high-temperature coke sold for house heating is rapidly increasing. In the types of heating equipment used in the United States there is not the same need for a fuel with the qualities of low-temperature coke that exists in lands depending largely on open fires. The typical house in the northern states is heated by a hot water or hot air furnace, placed in the cellar; the fire is lighted in the fall and kept going until spring. In such a furnace, coke of domestic size can be ignited without difficulty by first building a fire of paper and kindling wood. The low volatile content of high-temperature coke is thus a matter of small importance under American conditions, and largely for this reason interest in low-temperature carbonisation has centred on the recovery of oils and tar quite as much as on the production of domestic fuel.

American experience with high-temperature coke should, therefore, be of interest in all localities where the climate makes central house furnaces advisable. High-temperature coking has proved itself well adapted to mass production, and whatever may be the future of low-temperature carbonisation, the high-temperature oven has demonstrated its ability to produce a smokeless house fuel at relatively low cost.

Gas coke has long been a familiar domestic fuel in communities where the local gas supply is coal gas made in horizontal D-shaped or vertical retorts. As many communities are supplied with natural gas or with water gas[5] and as many others use a mixture of water gas and coal gas, the coke from the coal gas works being used for generator fuel in the water gas plant, the quantity of gas coke thrown on the market has been small measured by European standards. Excluding coke used by the manufacturer, the sales of gas coke amount to about 1,300,000 tons a year, most of which is used for house fuel.[6] Gas coke suffers from its softness and

[5] According to the statistics of the American Gas Association 58 per cent. of the manufactured gas distributed by public utilities for city supply in 1925 was water gas, 7 per cent. was oil gas, 19 per cent. was coke-oven gas, and 16 per cent. was coal gas made in horizontal or vertical retorts.

[6] U.S. Geol. Survey, Manufactured Gas and By-Products in 1920, by R. S. McBride, p. 477.

friability. It is subject to excessive breakage if shipped by railroad, and is usually disposed of locally at whatever prices can be obtained. It is irregular in size and often in quality, and as the gas retort is yielding place to the by-product oven as a means of making coal gas, the quantity of gas coke sold for domestic coke tends to decline.

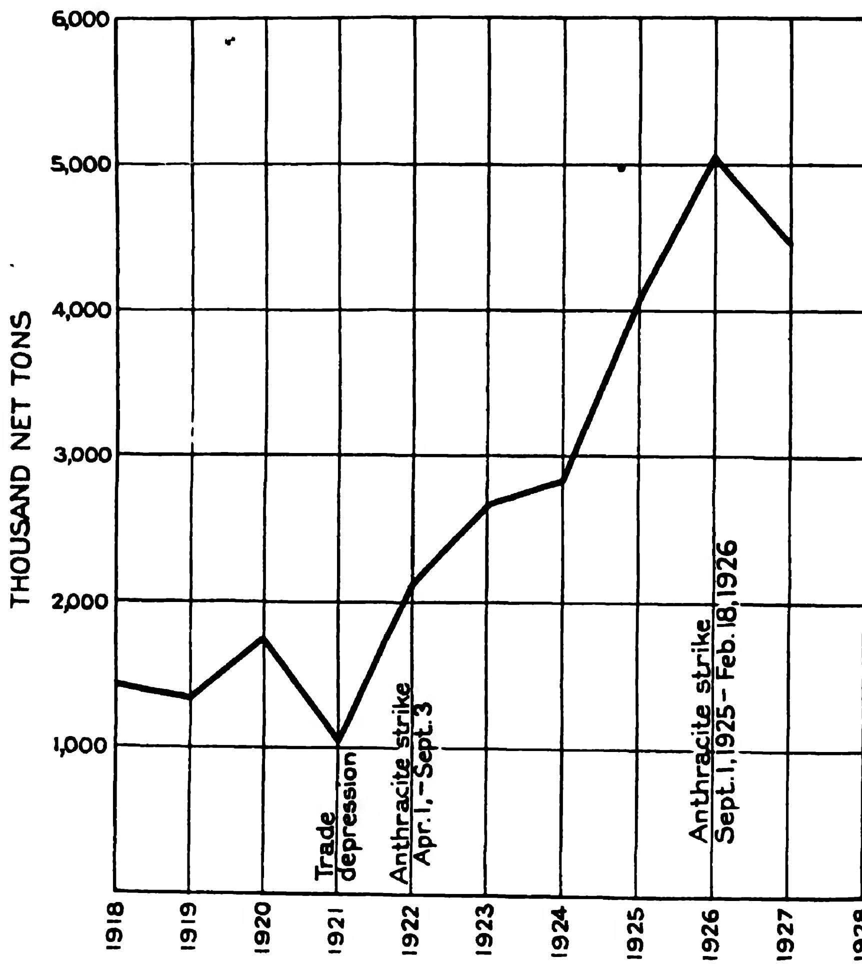

Fig. 1 By-product coke sold for domestic use in the United States, 1918-1927.

The figures for 1918 and 1922 exclude non-commercial deliveries of small coke to the employees of certain steel companies, and are not precisely comparable with those for the later years. The discrepancy, however, is immaterial. A new high record is expected in 1928.

DOMESTIC BY-PRODUCT COKE

Increase in Sales of Domestic By-Product Coke.—Coke made in by-product ovens is much harder and firmer than gas coke, can be crushed and sized, stands shipment by rail for distances as great as 800 miles, is more uniform in quality and brings correspondingly higher prices. The rapid increase in the quantity of by-product coke sold for domestic use, shown in Fig. 1, has been an outstanding feature of the fuel market in the United States. From 1,408,000 tons in 1918, the sales for domestic use increased to 5,057,000 tons in 1926. The demand in 1926 was stimulated by a strike of the anthracite miners, but in the following year, when anthracite was in abundant supply, the by-product plants marketed 4,703,000 tons of domestic coke, or three-and-a-half times the quantity of ten years before. Further increases in the tonnage of domestic coke are already apparent in 1928.

The rise of domestic by-product coke is associated with the rapid expansion of the by-product industry which began in 1914 and has continued since the war. Fully 85 per cent. of the capacity of existing American plants (including replacements of old ovens) has been added since August 1914, and in the construction of the new ovens advantage has been taken of the latest improvements in design. In comparison with the 21-in. ovens used in the pioneer days of the art, present-day ovens in the United States have been narrowed to 18, 16, or 14 in., with a more than proportionate reduction in coking time, and therefore in fixed charges per ton. At the same time, by increasing the height and the length, the capacity per oven has been raised from 6 or 8 tons to 10 or 12 tons. Larger unit charges and shorter coking time have together increased the daily output from 6 to 15 or even 18 tons of coke per oven per day. The ovens built since the War (1919-1927) have the following average dimensions and capacities:—

	Blast-furnace plants.	Alkali works.	Other merchant plants.	Total.
Number of ovens built ...	3,439	85	975	4,499
Length, ft.	39·4	40·9	35·2	39·0
Height, ft.	11·5	11·7	11·8	11·6
Width, in.	16·6	15·8	15·2	16·5
Oven capacity per charge				
Coal, tons	14·3	16·0	11·7	13·7
Coke, tons	10·1	12·0	8·4	9·7
Coking time, hours	15·9	20·0	13·9	15·6
Coke capacity per 24-hour day, tons	15·2	14·4	14·5	15·0

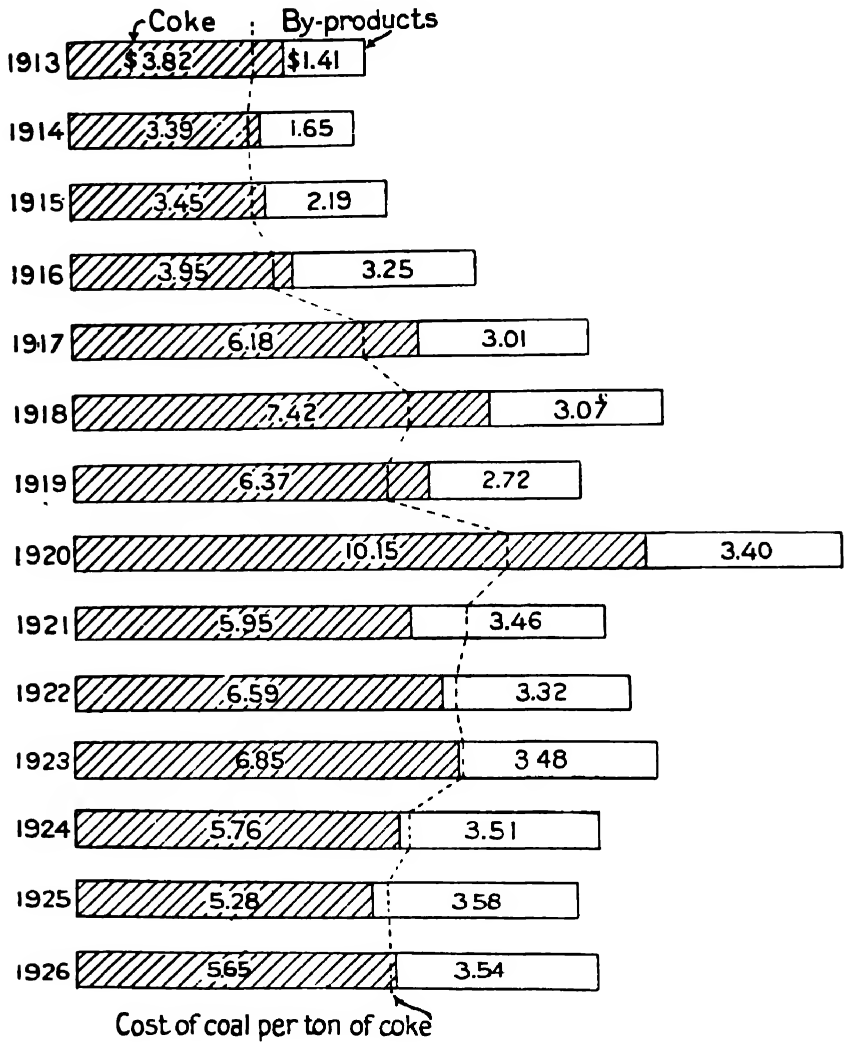

Fig. 2. Average value of by-product coke and value of all by-products and cost of coal per ton of coke produced.

In 1926, the average value of the coke produced at by-product plants in the United States was $5.65 per ton of 2,000 lb. (Shown by the shaded sections of the bars.) The value of the by-products (shown by white sections of bars) averaged $3.54 per ton of coke. The average cost of coking coal delivered at ovens per ton of coke produced is shown by the dotted line, and in 1926 was $5.55.

It should be noted that these figures represent the gross value of the products, and that there are many other expenses besides the cost of coking coal, including other materials, wages, salaries, purchased electric power, rents, insurance, taxes, and fixed charges on a very large investment (upwards of $500,000,000 for the industry as a whole). No data on total costs or profits have been collected.

Included among the group of "other merchant plants" are a number of installations of ovens much below the average in dimensions and capacity which have been made by city gas companies. A battery of eleven ovens installed in one northern city of 38,000 population has the following unit dimensions: length 23.7 ft., height 10.8 ft., width 13.5 inches, coke capacity per charge 4.4 tons, coking time 12.0 hours, and coke capacity per twenty-four hour day 8.8 tons. In a number of the plants the rate of coking averages 1.1 or 1.2 inches per hour.

With this increase in capacity per oven and the perfection of automatic machinery for charging coal and drawing the coke, the by-product oven has become a conspicuous example of economy of labour. Its costs have been so reduced that it can flourish even under the difficult market conditions of the United States, where the prices of tar and light oil are limited by cheap petroleum, and the price of gas by the potential competition of carburetted water gas.

Markets for Gas and By-Products. From 1913 to 1926 the total production of by-product coke increased from 12,715,000 tons to 44,377,000 tons, a growth of three-and-a-half times in thirteen years. The increase was stimulated by the changes in demand for the several products which began with the War. Fig. 2 traces the relative values of the coke and the by-products, and the cost of coking coal, all reckoned per ton of coke produced. Thus, in 1913 the average value of coke was $3.83, the value of the by-products per ton of coke was $1.41, and the cost of coal per ton of coke was $3.27. In 1926, the value of the coke had risen to $5.65 per ton, the value of the by-products to $3.52, and the cost of coal per ton of coke was $5.55. These figures, of course, represent merely the gross value of the products and a single item of cost; they take no account of the other costs of manufacture, such as wages, salaries, purchased electric power, insurance, taxes, and fixed charges on a very large investment. No data on total cost and therefore on profits have been collected, but the diagrams bring out clearly the trends of the market. Particularly important to the coke producers were the shifts in the values of the several by-products (Fig. 3). Increases in the value of tar and gas have more than offset a decline in the value of the benzols and ammonia, and the gross value of all the by-products reckoned per ton of coke is now much higher than before the War.

Changes in Prices of Domestic Coke and other Household Fuels.—The growth of the production of domestic coke has been facilitated by changes in price in relation to other household fuels (Fig. 4). The largest factor determining the retail price of coke is the price of anthracite delivered in the same community.

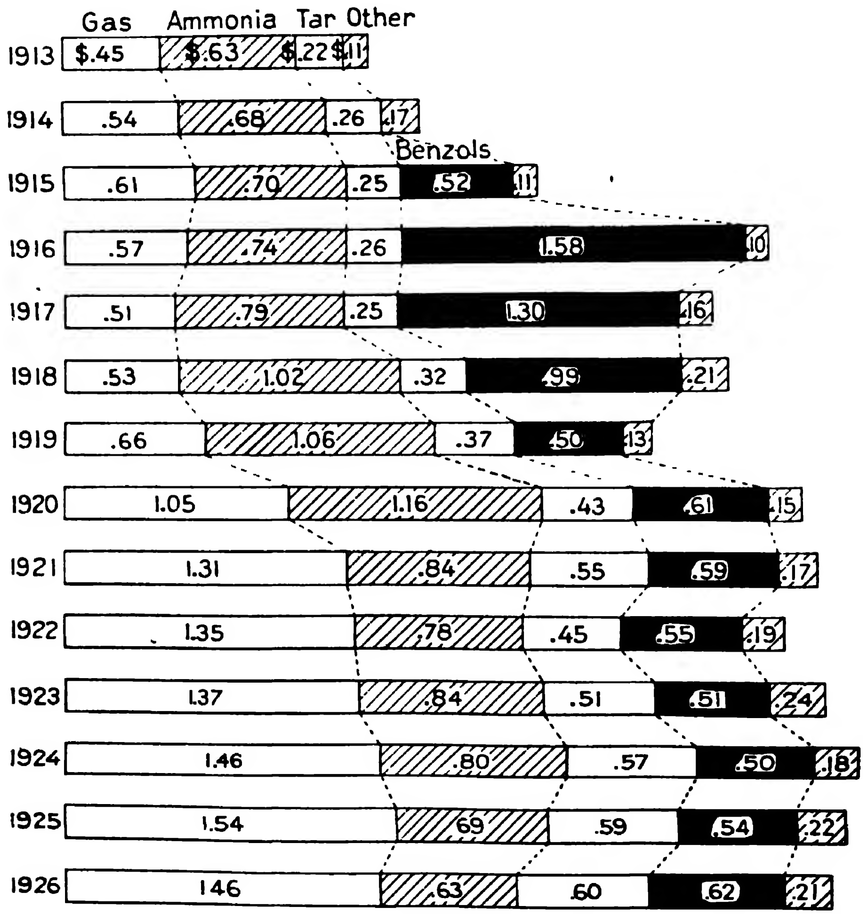

Fig. 3. Gross value of the several by-products per ton of by-product coke produced.

The data cover the operations of all by-product coke ovens in the United States. The data for gas represent the value of all gas not used in heating the ovens; for tar, both that sold and that used by the producer. Coke breeze is included under "other."

During the War, the benzol products furnished the largest revenue among the by-products. With the sudden decline in prices of benzol and toluol after the War, the benzol products have shrunk in value. Prices of ammonia have also declined. These losses have been largely offset by higher values for gas and tar, and the gross value of all the by-products was higher in 1926 than in 1916.

Whereas anthracite prices have advanced since 1920, because of increases in wage rates, the cost of coking coal delivered at by-product plants has been steadily declining. Lower costs of manufacture have in turn permitted a reduction in prices of domestic coke, thereby stimulating sales. Prices of fuel briquettes and of low-volatile bituminous coal have also declined.

Domestic Coke sold by Iron and Steel Companies.—The supply of domestic by-product coke is derived in part from plants associated with iron and steel works, known to the trade as "furnace" plants, and in part from the so-called "merchant" plants (see Table I). All but seven of the furnace plants are already equipped to screen and prepare their smaller coke for domestic use, the seven exceptions being in localities where the demand for house fuel is amply supplied by other means. In 1927 the domestic coke sold by plants affiliated with steel works

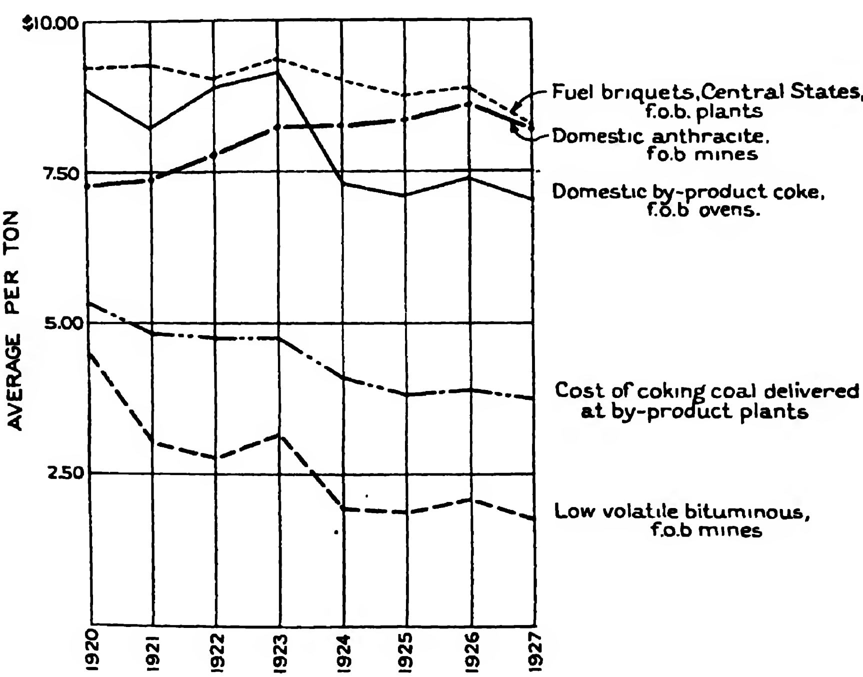

Fig. 4. Price trends of solid fuels suitable for household use, 1920-1927. Anthracite prices per ton of 2,240 lb.; all others, per ton of 2,000 lb. The figures for anthracite represent shipments from breakers (fresh mined), and include pea and larger sizes. Those for by-product coke include a small amount sold for miscellaneous industrial purposes. The figures for low-volatile bituminous coal are the average value per ton on all sales from three counties in Southern West Virginia.

amounted to 868,079 tons with a value f.o.b. ovens of $4,956,051, or $5.71 per ton. Ordinarily this coke is the residue left after the removal of pieces suitable for blast-furnace use, excluding, however, the breeze, which is separately reported. Much of this material is of the size known as pea, or less than three-fourths of an inch in diameter, and although usable for domestic heating, it brings a lower price than the larger sizes known as egg, stove, and nut, which are especially prepared for domestic use by the merchant plants. A number of the steel companies make a practice of disposing of their domestic coke to their employees at nominal prices; others sell the surplus on the open market for such prices as they can obtain, sometimes directly and sometimes through middle-men. For these reasons, the average returns obtained by the steel works for their domestic coke are generally much lower than those obtained by the merchant plants.

TABLE I.

SALES OF DOMESTIC BY-PRODUCT COKE IN 1927 BY PLANTS ASSOCIATED WITH IRON AND STEEL WORKS AND BY MERCHANT PLANTS.

Type of plants	Net tons	Value at plant*	Average per ton
Plants affiliated with iron and steel works	868,079	$4,956,051	$5·71
Merchant plants	3,834,450	27,491,888	7·17
Plants engaged largely in supplying gas for city distribution	2,169,674	17,393,323	8·02
Other merchant plants	1,664,776	10,098,565	6·07
Grand total ...	4,702,529	$32,447,939	$6·90

* Excludes costs of merchandising and delivery to consumer.

Merchant Plants.—As the steel companies have now generally equipped themselves with by-product ovens, no great increase in the tonnage of domestic coke offered by furnace plants is expected, and further expansion in the supply must come chiefly from the non-furnace or merchant ovens. In 1927 the merchant plants sold a total of 3,834,450 tons for domestic use, with a value f.o.b. plant of $27,419,888, or $7.17 per ton. This group includes a few plants affiliated with alkali works, a small number whose main business is the production of blast furnace coke but which have no direct affiliation with iron and steel companies, and

a much larger number of plants built to supply gas for city distribution, sometimes owned directly by the public utility company distributing the gas, but more often separate corporations operating as private companies and selling the gas under contract to the public utility distributor. These plants are prepared to make blast furnace coke where the market demands it, but engage chiefly in the manufacture of foundry coke, domestic coke, and coke for miscellaneous industrial uses, the chief of which is water gas. A number of them sell nearly their entire output as domestic coke.

A major problem in the operation of the merchant plant is to adjust its production of coke to the demands of the market at the same time it is fulfilling its contract to furnish gas. Flexibility of operation has been introduced by the practice of heating the ovens with producer gas or blue water gas when the demand for gas is at a maximum, thereby releasing the entire supply of coke oven gas for sale and at the same time reducing the quantity of coke to be disposed of by using the smaller sizes in the gas producer or water gas generator. Conversely, when the demand for the gas is at a minimum and the market for coke active, the ovens are heated with coke oven gas, thereby diminishing the surplus gas and increasing the amount of coke available for sale. By this means, the relative proportions of gas and solid fuel produced for sale may be varied at will within limits. This single development has greatly widened the field open to the by-product coke oven.

Size of Merchant Plants.—The larger of the merchant plants include installations of from 100 ovens to as many as 250 or even more. Plants of this size have naturally been located near large centres of population, such as Boston, New York, Buffalo, Detroit, Chicago, Milwaukee, Indianapolis, and Birmingham, where a market exists for both coke and gas. Seven of the merchant plants produced over 500,000 tons of coke in 1927.

There have also been successful installations on a small scale. Six plants of less than twenty ovens operated in 1927, with an average production of 34,600 tons each (Table II). These small plants include a number built within the last four years. By suitable modifications in design, the by-product oven is now adapted to use in communities of from 50,000 to 20,000 population, as shown by recent installations in Michigan, Massachusetts,

and New York State. Experiments with still smaller installations are being made.[7]

TABLE II.—CLASSIFICATION OF MERCHANT BY-PRODUCT COKE PLANTS ACCORDING TO NUMBER OF OVENS IN 1927

Ovens per plant.	Number of plants.	Annual production of coke per plant. (Net tons)	Annual sales of domestic coke per plant. (Net tons)	Per cent. of production sold for domestic use.
Less than 20 ovens	6	34,600	18,400	53·3%
20-29 ovens ...	*5	60,600	5,800	9·6%
30-49 ,, ...	6	134,000	46,500	34·6%
50-99 ,, ...	7	268,000	111,000	41·5%
100-199 ,, ...	8	456,000	171,000	37·4%
200 ovens and over	4	733,000	320,000	43·6%
Total and averages	36	272,000	106,400	39·2%

*Includes one plant which started operations late in year and one gas-company plant which sold all its product for blast-furnace use.

Properties of Domestic Coke. Representative analyses of coke made for domestic use as reported by the manufacturers show a volatile content of from 0.7 to 2.0 per cent., sulphur from 0.6 to 1.5 per cent., ash content from 7 to 15 per cent., and a fusing temperature of ash ranging from 2,300° to 2,800°F. A few installations operated by city gas companies report a volatile content of 3 per cent., but as already stated, the percentage of volatile matter is found to be of small importance under American conditions. Practically, also the percentage of sulphur is not a matter of concern as any coal meeting the requirements of gas manufacture or metallurgical use will also satisfy the domestic trade in this respect. A low ash content, on the other hand, is a great advantage. According to Rose, "In some cases coals less than 6 per cent. ash are regularly used and the 8 or 9 per cent. ash coke is suitable . . . . for the most strongly competitive markets. Domestic cokes containing 10 to 15 per cent. ash may be classed in most localities as good to fair, respectively. Nut-size coke of still higher ash content is produced by some plants, but it is not made with the requirements of the domestic trade in view and is usually sold at a considerably lower price than first quality domestic coke."[8]

[7] McBride, R. S. Miniature coke ovens to serve the small community, *American Gas Journal*, July 1927, pp. 27-31.

[8] Rose, H. J. The selection of coals for the manufacture of coke; American Institute of Mining and Metallurgical Engineers; paper presented at February 1926 meeting, p. 36.

Another factor of great importance is the fusing temperature of the ash; coke with a low fusing temperature produces clinkers in the domestic furnace and leads to many complaints. In general, the higher the fusing temperature the better, and many plants supplying the domestic trade aim to keep the fusing point at from 2,500° to 2,800°F., although there are other cokes with a favourable reputation in the localities served in which the fusing point is as low as 2,300° to 2,400°F. "The American Society for Testing Materials standard specifications for gas and coking coals, give 2,200°F. as the minimum, but this is unquestionably a low limit."[9]

Sizes Sold. Coke designed for the domestic trade must be carefully screened to remove all the breeze and sized to meet the requirements of the local market. All plants making a speciality of domestic coke are equipped to crush and size the product. The sizes most commonly made are egg and nut, although stove and pea are also prepared. The dimensions of these sizes are not uniform, but the following will indicate the approximate limits: egg, 3 to 2¼ inches; stove, 2¼ to 1¼ inches; nut, 1¼ to ¾ inches; pea, ¾ to ½ inch. Where only two sizes are prepared, the egg commonly includes the stove as given above and the nut commonly includes the pea. Differentials are introduced in the retail prices on several sizes depending on the local market. In general, egg and nut bring about the same price, with egg sometimes 25 cents to 50 cents higher, while pea usually sells for about $2.00 a ton less.

The prices obtainable for coke vary with the locality, the largest factor in determining the price being the cost of other fuels. In the regions where anthracite is the established fuel, coke must usually be offered at a price from $1.00 to $2.00 a ton less.

Distribution. Plants located within motor trucking distance of the communities they serve are in a position to make deliveries direct to householders' cellars, with consequent saving in the cost of rail transport and in the breakage involved in loading and unloading the railroad car. The percentage handled in this way varies greatly. A number of the newer plants built primarily to serve the househould trade and furnish city gas, dispatch the bulk of their domestic coke by truck. One company selling 150,000 tons of domestic coke delivers it all by truck within a

[9] Rose; work cited, p. 37.

radius of 10 miles from its plant. Still other companies, not so favourably located for trucking, ship all their coke by rail. Deliveries to retail coal dealers are usually made by rail (or barge in port cities) even when the dealer's yard is in the same city as the plant. Some coke companies have established retail yards of their own, to which they first ship by rail, making the local delivery by motor-truck.

A coke plant is by no means limited to the local market, however, for by-product coke is hard enough to endure shipment without undue breakage. Each plant tends to become a centre of distribution, supplying first the local market and then spreading out into the surrounding territory. The radius of distribution may be from 50 miles to 500 miles, depending on the competition of other fuels, particularly on coke from other plants. Indeed, there are plants in the South where the local market is small, that ship domestic coke to distances of 600 or even 800 miles.

Marketing Problems. Except for plants located long distances from satisfactory markets, the producer seldom utilises a wholesaler in marketing his domestic coke, and either sells it directly himself or through an affiliated sales company.

With respect to retailing, policy varies widely. One company with a long-established business in the Middle West sells 96 per cent. of its domestic coke through retailers. Another, recently established on the Atlantic Coast, sells only 2 per cent. through retailers and places 98 per cent. of its tonnage direct with the householder. Most companies occupy a position somewhere between these extremes. In communities where coke is well known in the retail trade, the producer is usually glad to utilise the coal merchants already in business. To introduce coke in a new community, on the other hand, requires much sales effort, and this the producing company usually finds it advisable to undertake itself. Later, when the demand has been created, the local retailers are often in a position to give effective service.

In addition to advertising, it is necessary to do much patient work in assisting the consumer to select the size best suited to his equipment, and in teaching him the proper methods of firing. Dependable service must be maintained and complaints given immediate and personal attention. No attempt is made within the limits of this paper to describe the methods recommended

for burning coke or to discuss its relative merits in comparison with soft coal, or anthracite. It will be apparent, however, that the greater volume of coke per unit of weight necessitates different methods of firing, and that the expansion of the domestic market in recent years has required a sales effort of no small proportions.

Possible Further Expansion. Over the United States as a whole, coke now supplies about 5 per cent. of the total consumption of domestic fuel. In the Northern cities in which by-product coke plants have been built, the proportion is much higher, ranging from 7 per cent. in some of the largest cities to 25 per cent. in one city of 270,000 population, and as high as 30, 40, or even 50 per cent. in certain of the smaller communities. Cities with no local supply, on the other hand, use smaller percentages of coke and often rely almost entirely on other fuel. The consumption of coke is thus very unevenly distributed, and further expansion depends largely on the construction of new by-product plants in localities where the potential market for coke has not yet been developed.

The construction of new plants, however, turns also on finding outlets for the gas. Without a balanced demand for both coke and gas within the radius of economic transmission, the coke oven can hardly compete. Its adaptability to mass production and the degree of flexibility introduced by heating the ovens with producer gas have made it an efficient means of producing city gas, but it will be installed only where the net cost of gas, all credits considered, is less than the cost by alternative methods of manufacture. The final choice can be determined only after consideration of local conditions.

In comparison with coal gas retorts, the advantage is usually with the coke oven, because its savings in labour cost more than offset the higher fixed charges.[10] In comparison with water gas the decision turns on a number of factors, among which is the fluctuating price of oil for carburetting. Suffice it to say that under many conditions the coke oven has become the most economical source for base-load city supply. In 1921, coke ovens furnished only 11 per cent. of the manufactured gas distributed for city use; in 1926 their share had increased to 20 per cent. Since January 1, 1926, there have been nine installations of

[10] McBride, R. S.; work cited, p. 31.

by-product ovens for city gas manufacture and five more are now under construction, including a plant at Montreal, Canada. (Table III.)

TABLE III.

BY-PRODUCT COKE OVENS DIRECTLY SUPPLYING CITY GAS COMPANIES BUILT SINCE JANUARY 1, 1926, OR UNDER CONSTRUCTION AT THE PRESENT TIME[1]

Company and location.	Number of ovens.[2]	Type of ovens	Annual coal capacity[2] (net tons).	Annual coke capacity[3] net (tons).
1926.				
Consolidated Gas Co., New York, N.Y. ...	74	Koppers-Becker	638,750	447,125
New England Fuel and Transportation Co., Boston, Mass	51	Wilputte "	372,000	260,000
Rochester Gas & Electric Co., Rochester, N.Y.	37	Koppers-Becker	170,000	119,000
Utica Gas & Electric Co, Utica, N.Y. ...	21	Koppers-Becker	100,000	70,000
1927.				
Battle Creek Gas Co, Battle Creek, Mich.	7	Koppers-Becker	35,000	25,000
Citizens Gas Co., Indianapolis, Ind. ...	40	Wilputte	197,000	138,000
Consumers Power Co., Flint, Mich. ...	29	Koppers-Becker	118,000	83,000
Rochester Gas & Electric Co., Rochester, N Y.	23	Koppers-Becker	104,000	73,000
West Boston Gas Co., Framingham, Mass.	15	Koppers-Becker	47,523	33,266
1928.				
Connecticut Coke Co., New Haven, Conn.	61	Koppers-Becker	416,000	291,000
North Shore Coke & Chemical Co., Waukegan, Ill.	31	Koppers-Becker	165,000	116,000
Montreal Coke and Manufacturing Co., Montreal, Canada	59	Koppers-Becker	450,000	315,000
Brooklyn Union Gas Co., Brooklyn, N.Y.	74	Koppers-Becker	691,310	483,917
Philadelphia Coke Co, Philadelphia, Pa....	74	Koppers-Becker	728,000	510,000

[1] Note that no figures are given for plants not supplying city gas companies. The total number of new ovens, built in 1926 (excluding replacements), was 426, and in 1927 it was 759.

[2] The figures as to number of ovens and coal capacity are taken from a paper by C. J. Ramsburg presented June 14, 1928, before the National Fertilizer Association, supplemented by data in *Iron Age*, January 26, 1928, p. 268.

[3] Computed from preceding column, assuming an average yield of 70 per cent.

House-Heating with Manufactured Gas

At the same time that the use of domestic coke is growing, a parallel development in the heating of houses with gas is tending to expand the outlets for manufactured gas. Although the number of houses heated with gas is still very small, the movement has passed the experimental stage and is increasing at a rapid rate. In the State of Massachusetts, 1740 homes are now heated with gas, an increase of 690 over last year.[11]

[11] Massachusetts Special Commission on the Necessaries of Life, Summary of fuels used for heating homes in Massachusetts, May 16, 1928.

The city of Baltimore will serve as an example of the development of gas heating. The first installation was made fourteen years ago. There are now 1,700 houses heated with gas—less than 1 per cent. of the total number in the city—and the number of installations has been increasing at the rate of 200 a year. The gas is a mixture of 50 per cent. water gas and 50 per cent. coke-oven gas, obtained from a near-by steel works, and is sold for house heating at approximately 65 cents per M cubic feet. The consumer desiring to heat with gas must go to the expense of installing a special furnace, and the price of the gas according to the company is equivalent to coal at $22. a ton.[12] The extra investment in the furnace and the high cost of the fuel indicate that gas heating is a luxury, but it is evidently a luxury for which many families will gladly pay in order to be rid of the dust and smoke of bituminous coal and the labour of stoking the fire and handling ashes. The gas furnace is an example of the tendency toward automatic heating, which is perhaps the most interesting development in the field of household fuel in the United States. Of this development more will be said in discussing the use of fuel oil.

PART II—DOMESTIC HEATING FROM COALS BELOW THE RANK OF ANTHRACITE

F. M. SHORE

The production figures of the United States specify two classes of coal—bituminous and anthracite. The figures for bituminous include the bituminous rank, comprising the great bulk of the production, and its related types, semi-bituminous and sub-bituminous coals. It also includes semi-anthracite and lignite coals, both of which amount to only a fraction of one per cent. of the total bituminous production reported annually. The annual bituminous production, thus grouped, has ranged from 415,922,000 to 573,367,000 net tons since the World War, with an average annual production of 503,799,000 net tons.

No records of the production of bituminous coal are available prior to the period covered by the years 1807 to 1820, the production of which is estimated at but 3,000 net tons. Since that period production has increased gradually to the high record of

[12] This computation assumes a much higher efficiency in the special gas furnace than is obtained in the coal furnace.

579,385,820 tons in the year 1918, and the annual record ends with the preliminary figure of 519,804,000 tons in 1927. Bituminous coal has for many years been the chief industrial fuel of the country, and the basic source of energy which has made possible the great industrial and commercial development which the nation has achieved. In addition, it is also the most widely used of domestic fuels.

Estimates based on a number of investigations conducted by the U.S. Fuel Administration placed the consumption of bituminous coal for domestic heating in 1917 at 57,104,000 tons, or 10 per cent. of the production of that year. These figures include the fuel used for heating dwellings, hotels, apartments and office buildings, of the five ranks of coal grouped under bituminous production. A later estimate by the Bureau of Mines placed the consumption of bituminous coal for domestic heating at 66,400,000 tons in 1923, or 12.8 per cent. of the production in that year. It is safe to say that the annual consumption of bituminous coal for domestic use still ranges from 10 to about 12 per cent. of production, the variation depending chiefly upon differences in the severity of the weather during the coal-burning season.

Coals of the bituminous group are used for domestic heating in all of the States and in the District of Columbia, although there is a wide range of the per capita use from the southern border of the country with its semi-tropical climate to the northern states with their long and severe winters.

The consumers' choice of a coal for domestic use is, of course, governed largely by delivered price. As the bituminous coals are produced in many of the States, their proximity to a large percentage of the consumers of the country is responsible for their widespread use. This condition promises to prevail for many years, with such modifications as may arise from an increased use of oil and gas, or coke, and other manufactured fuels. Because of their wide geographical availability the bituminous coals predominate from the Alleghany region of the East to the Pacific Coast. The general higher quality of the eastern coals enables them to encroach somewhat on the natural market territory of the coals of the middle states, and some coal from the Alleghany Region penetrates even beyond the Mississippi River.

The general characteristics and position of those ranks of coal grouped in the production figures under the term "bituminous," all of which are used for domestic heating within the consuming

territories accessible by reasonable distance and freight rates from the producing mines, are briefly as follows:—

Semi-anthracite coal, in the official classification of the U.S. Geological Survey,[13] is the rank next below anthracite. Its fuel ratio (percentage of fixed carbon divided by percentage of volatile matter) is just over 5 and up to 10.[14] Its hardness is between anthracite and bituminous. It ignites more readily than anthracite, and the small amount of smoke produced in its combustion makes it an acceptable household fuel. Production of semi-anthracite occurs principally in Virginia, Arkansas, and in a small field adjacent to the anthracite fields of Pennsylvania. While not a large item in the total of domestic heating coals produced in the United States, the use of semi-anthracite is expanding, and its distribution to wider markets increasing.

Next below the rank of semi-anthracite are the semi-bituminous coals, which occur in abundance in Southern West Virginia and South-western Virginia, Northern Maryland, and in the South Central part of Pennsylvania. These are also produced in smaller quantities in Arkansas and Oklahoma and a few other states. These coals have a fuel ratio ranging from just above 2.5 to 5. They have a high heating value, generally a high ash-fusing point, and are low in volatile matter, resulting in very little smoke when burned in ordinary furnaces. Because of these characteristics, semi-bituminous coals have increased in popularity for domestic heating in recent years, which movement has been stimulated during the two long suspensions of anthracite production by labour difficulties in 1922 and 1925-1926, and by organised sales campaigns by the producers. Their smokeless characteristics have contributed greatly to the growing use of these coals in cities and towns where smoke-prevention regulations prevail. The semi-bituminous coals are friable in nature, and the amount of lump coal in the mine run is approximately 30 to 40 per cent. While the run of mine is burned generally in the heating plants of office buildings, hotels, and apartments, and can be burned successfully in domestic heating equipment of individual homes, little of it is used in this form by the small domestic consumer, who prefers the prepared sizes commercially known as lump, egg, and stove.

[13] Professional Paper 100-A. The Coal Fields of the United States.

[14] Carnegie Institute of Technology. Proceedings of the International Conference on Bituminous Coal, 1926. Campbell, Our Coal Supply: its Quantity, Quality and Distribution.

The bituminous rank furnishes the largest element in the annual coal output of the United States. It is produced in abundance in twenty States, from Pennsylvania, Maryland, and the Virginias in the East, to Washington on the Pacific coast. Most of the bituminous coal is produced east of the Mississippi River. Coals of this rank have a fuel ratio above that of sub-bituminous coal and up to 2.5 inclusive. For domestic heating the use of bituminous coal is as widespread as its production, as its proximity to a large population makes it the most economical fuel to a large percentage of the people. Probably 40 per cent. of the bituminous coal consumed for domestic heating is used in the thickly populated territory lying north of the Ohio River and east of the Mississippi River. While there is considerable range of quality in the bituminous coals of the United States, mostly they are hard in character, produce a good percentage of the prepared sizes which are preferred by the individual consumer, are low in ash, burn with a long flame and develop a strong heat.

The sub-bituminous coals follow next in the descending scale. These coals are similar to those designated "black lignite" in some other countries. They are high in moisture and slack, or disintegrate when exposed to weather. They must, therefore, be shipped in box cars to protect them from the weather, and even then they cannot be marketed economically at a long distance from the mines. They are produced in abundance in the Rocky Mountain States of Montana, Wyoming, and Colorado, and to some extent in Washington and New Mexico. These coals are clean to handle and are used largely as a domestic fuel.

The lowest in rank of the United States coals is lignite, which is brown in appearance, woody in character, with 25 to 45 per cent. of moisture, and slacks or breaks up on exposure to weather. It cannot, therefore, be shipped long distances economically and is used chiefly as a domestic fuel. Lignite is mined mainly in the State of North Dakota, which produces annually slightly less than a million and a half tons, and in Texas, which produces slightly under a million tons annually.

PART III—HEATING WITH OIL

E. B. SWANSON

Oil has been used as a fuel in the heating of buildings in the United States for nearly fifty years, but its widespread utilisation and its application to domestic heating are distinct developments

of the latter half of the post-war period. On the Pacific coast and in portions of the Middle West, oil has been used as a fuel for several decades, but along the Atlantic coast and particularly in the cities from Portland, Maine, to Washington, D.C., the most rapid strides have been made only within the past five or six years.

The first installations were made chiefly in existing boiler plants where coal had previously been burned. The experience thus gained established the possibilities of oil burning, and it has been given careful consideration by architects and builders in planning new structures. During the war period, building programmes were suspended or postponed in order that material and labour might be diverted to strategically more important purposes. When the United States had recovered from the post-war depression of 1921, a national enthusiasm for building concentrated within a few years all of the construction which might ordinarily have been spread over a number of the preceding years.

During the period of suspended building, crude oil production in the United States increased from 335,000,000 barrels in 1917 to 732,000,000 barrels in 1923, with the result that an ample supply of oil was available coincident with the renewal of building activity. The inherent qualities of oil as a fuel in urban heating, coupled with the development of improved burners and definite sales stimulation by oil producers and burner manufacturers, resulted in a widespread adoption of oil as a fuel for commercial and domestic heating. Oil burning has been adopted in boiler plants of every type and size, from that of the central station, factory, office building, hotel, apartment house, hospital, theatre, and school, down to the smaller heating plants, such as used in the private home.

It has been estimated that three per cent. of the total fuel oil produced in the United States during 1925 was used as fuel for heating homes and buildings. According to actual statistical information obtained through national surveys of fuel oil distribution, this percentage increased to 4.5 in 1926 and to 5.3 in 1927.

The consumption of oil in commercial and domestic heating in the United States during 1927 was approximately 26,350,000 barrels. As it is difficult to comprehend the significance of such mathematical presentation, it might be said that this quantity of

oil was the approximate equivalent of the 1927 crude oil production in Rumania and was equal approximately to the total fuel oil consumption in Great Britain during 1927, including the oil delivered to ships' bunkers.

Three groups of States, which may be described as the North Central, the North Atlantic and the Pacific Coast areas, consume virtually all of the oil which is burned within the United States for the heating of buildings. The following table shows the approximate quantity of oil consumed and the major regional distribution :—

OIL CONSUMED FOR HEATING OF BUILDINGS IN UNITED STATES

Regional Distribution	*Barrels*
North Atlantic States	11,300,000
Central States	10,100,000
Pacific Coast area	4,500,000
South Atlantic States	450,000
Total 1927 consumption	26,350,000
Estimated 1926 consumption ...	23,700,000

Of the total oil consumption for heating of buildings, approximately 11,000,000 barrels were consumed in the heating of residences and the balance, 15,350,000 barrels, in the heating of commercial structures. Although domestic oil heating is a development of the past few years, its rapid application is indicated by the following table showing annual estimated consumption :—

OIL CONSUMPTION FOR DOMESTIC HEATING

Year	*Barrels*
1923-24 season	2,818,000
1924-25 season	5,021,000
1925-26 season	8,829,000
1926 calendar year	9,080,000
1927 calendar year	11,000,000

The normal heating season begins when daily mean temperature goes below 60°F. and ends when daily mean temperature goes above 60°F. Based upon U.S. Weather Bureau records of the past forty-six years, the normal heating season in New York City begins on October 10 and ends on May 10. The normal fuel

requirements per month in per cent. of total requirements for the heating season are shown in the following table:—

MONTHLY NORMAL HEATING REQUIREMENTS—
NEW YORK CITY

Month	*Per cent.*
October	3.5
November	11.0
December	19.0
January	21.0
February	20.0
March	16.0
April	8.0
May	1.5

Being without commercial deposits of coal, early industries in California depended upon coal shipped from Australia, British Columbia and the State of Washington, while experiments were being carried on with the use of oil as fuel. Even as early as 1883, oil was burned as a fuel on the Pacific Coast in heating some of the larger hotels and office buildings. Through these early experiments, the problems of burning and storing were met successfully, and oil was being burned for various purposes when the Kern County discoveries in 1899 made available in California the additional supplies necessary for increased use.

In the North Central States, oil was burned as a fuel for a number of purposes, including the heating of buildings, prior to 1888, and also was used at the World's Columbian Exposition in Chicago in 1892 and 1893. The burning of oil as a fuel in this area undoubtedly was stimulated through the marketing of the fuel oil which was produced by the large refineries located on the Great Lakes. As the technical programme of these refineries was altered to meet, through cracking, the increased demands for gasoline, the proportional output of fuel oil was decreased and the markets which had been developed were then supplied by the shipment of fuel oil in tank cars from the refineries in the Mid-Continent area.

The development of fuel oil markets in the North Atlantic States, including New England, is of more recent date than in the two other principal burning regions. The presence of large refineries in this area, coupled with the ease with which oil may be transported by tanker to shore communities, assured this region of an adequate oil supply. The cities of Boston and

Providence were the first communities in this area to adopt oil burning. A few large residences in these two cities burned oil prior to the war, but these installations were exceptional in that 14-16 gravity oil was burned and they were manually operated by the caretaker. New York City was relatively slow in taking up the use of oil fuel, but after regulations making it possible to install plants were adopted about seven years ago, conversions from coal to oil went ahead with great rapidity. The nationally known Singer Building was first to adopt oil. In Boston, one of the first plants to change over from coal to oil was the Harvard Medical School power plant, which furnishes heat, light, power and refrigeration for a group of thirty-four hospital and college buildings. In Providence, R.I., virtually every building of prominence is burning oil. The real growth in oil burning in this area began about 1920.

Although oil is of adequate supply in the Southern group of States, including Texas, Louisiana and Oklahoma, the equally adequate supply of natural gas in this region has resulted in the use of this fuel for industrial and commercial purposes, and oil burning at stationary plants has not been developed to the same degree as in some other sections of the United States. This, also, is true of Southern California, where natural gas is a favoured domestic fuel. In these two regions, however, oil is being burned as a fuel for mobile purposes, railroad and steamships, almost to the exclusion of other fuels. In the Pacific North-west, where wood and sawmill waste have been the predominant domestic fuels, oil recently has been adopted, owing again to the adequacy of the California supply and the ease of shipment by tanker to sea ports of the Pacific North-west.

The use of fuel oil for industrial heating established the fact that oil offered opportunities for precise control, either automatic or manual, that could not be obtained with solid fuels. The cleanliness, lack of waste, freedom from smoke and soot, and the opportunities for applying automatic or semi-automatic control established the desirability of this fuel for commercial buildings. The subsequent application of these principles to automatic domestic oil-heating equipment was an obvious development.

Oil burning in the heating of buildings usually is divided into two classes, commercial and domestic, depending upon whether the operations are manual or automatic respectively. In other

words, commercial burning requires the presence of an engineer, mechanic, or caretaker, while domestic burning may be entirely automatic or require only the occasional attention of the householder. Some of the larger residences in the United States are equipped with heating plants similar to those installed in small apartment houses and require the attention of an engineer. This type of residence heating virtually is identical with commercial heating.

Burners designed for house heating may be classed either as vaporising, comprising the so-called gravity-feed type, or atomising, including those in which the oil is broken up by passing through a small orifice under pressure; by centrifugal force from the edge of a rapidly rotating cup or disc; or other equally effective methods.

The automatic operation of domestic oil burners depends upon control mechanisms, which will shut off the burner and again ignite the flame as required. Ignition of the flame may be accomplished by a gas pilot, an electric spark, a combination of electricity and gas, or occasionally by means of an oil torch.

The uniform fuel oil specifications of the American Oil Burner Association classify fuel oils by numbers ranging from one to six. Oil No. 1 is a light furnace oil, with an approximate gravity range from 36°—45°; Oil No. 2 is a medium furnace oil, gravity ranging from 32°—36°; and Oil No. 3 is a heavy furnace oil ranging from 28°—32°. These three oils are commonly used for domestic heating, as they do not require pre-heating and are susceptible to the fully automatic control, which is essential to the operation of an oil-burner in a private home.

Oils No. 4, 5 and 6 are called fuel oil—light, medium and heavy, respectively, and range from 24 gravity to 12 gravity and heavier. They require heating because of their higher viscosity at normal temperatures and are used only in large commercial and industrial installations, where manual operation is desirable. This situation occurs in the larger office buildings, apartment houses and hotels, where a janitor or mechanic is on hand at all times to make the necessary adjustments and to start and stop the burners. The fuel oils are less expensive than the furnace oils, but the installation of heating equipment in the tanks and near the burners adds to the initial cost.

Furnace Oil No. 3, also, is known to the trade as a light fuel oil, intended for special industrial consumption where a high

quality low viscosity fuel is required. This oil usually is sold to the domestic consumer at approximately two cents a gallon less than Furnace Oil No. 1, and most of the modern domestic oil burners have been designed to burn satisfactorily this grade of oil. A limited number of domestic oil burners are designed for the use of a 24° gravity fuel oil and some are restricted in their use to Oils No. 1 or 2. A definite trend is noticeable toward the heavier oils (28°—32°) both in the design and manufacture of oil burners and the resulting consumption of oil.

Earlier types of burners were objected to on a basis of odour, noise and lack of mechanical perfection. These objections have, in the main, been overcome, and burner manufacturers stress the features of silence and automatic operation in respect to their individual burners. The relative costs between oil and other fuels vary with each locality and can be considered only through an analysis of the factors affecting the individual instance. General statements with respect to relative costs are of little value. It is interesting to note in this respect that, despite the present low scale of fuel oil prices, constructive sales arguments are not based on relative costs, but upon the advantages or qualities which are inherent within the fuel.

Recurring doubts as to the adequacy of the oil supply have had undoubted effect in the past upon the willingness to adopt or convert to oil heating. This factor was of major importance during the high-price period of 1920 until the discoveries in Southern California during the latter part of 1922 resulted in enlarged crude oil production. The more recent discoveries of new fields and the present potential domestic and foreign production have done much to eliminate this particular "doubt." The willingness of marketers to make longtime contracts at present fuel oil prices has assisted, as well, in eliminating the present fear of oil shortage.

The American Petroleum Institute, an association of individuals directly affiliated with the petroleum industry, during its 1927 annual meeting adopted a resolution which reflected full faith in the ability of the oil industry to meet the growing demand for oil for domestic heating purposes.

Definite stimulation of domestic oil burning has resulted from the publicity programmes instituted by the American Oil Burner Association and its affiliated Oil Heating Institute. The

Association was organised in September, 1923, to serve as a clearing house for information pertaining to types and designs of burners, specifications for burning oils, installation and operation of burners; to assist in the standardisation of municipal ordinances pertaining to the installation of burners and storage tanks; and other related services.

The American Petroleum Institute recently has joined with the Oil Heating Institute in a major publicity programme which contemplates the expenditure of $350,000 during 1928 for a series of advertisements in prominent national magazines, through which it is estimated that the facts pertaining to oil heating will be presented to more than 8,000,000 families. The costs of this campaign are being shared equally by the manufacturers of oil burners and the oil industry.

The Committee of the American Petroleum Institute which recommended the participation of the oil industry in this publicity programme summarised its reasons as follows:

> "In view of the continually increasing productive capacity of the industry, the urgent need of developing new uses and new markets for petroleum and its products has become apparent. Fuel oil is in greatest over-supply. The heating of dwellings and commercial buildings with oil appears to offer the best opportunity for immediate and rapid market expansion. If superior use be an element of a sound conservation programme, the use of fuel oils and distillates for so-called domestic heating is not antagonistic to sound conservation."

RÉSUMÉ

Dans la partie des Etats-Unis accessible sans difficulté aux mines de la Pennsylvanie orientale, l'anthracite, depuis longtemps le combustible type pour le chauffage des domiciles, répond admirablement à ce but parce qu'il ne fume pas en brûlant ni dépose de la suie, donne lieu à peu de poussière et donne un feu qui se règle avec le minimum d'attention. Il y a, cependant, beaucoup de régions où l'anthracite est trop coûteux pour le consommateur ordinaire, principallement à cause des frais de transport. Dans ces régions le développment d'un combustible quelconque qui serait plus propre que la houille grasse ordinaire est un problème de grande importance.

Une des premières tentatives à une solution du problème consistait en le briquettage de la poussière d'anthracite ou des déchets de criblage de la houille grasse à basse volatilité. Bien que les combustibles bruts

employés par les installations de briquettage soient "sans fumée," les liens de brai en usage émettent une fumée désagréable. Les procédés de briquettage plus compliqués, par lesquels la fumée du lien s'élimine, sont plus coûteux et sont en concurrence avec l'anthracite nouvellement abattu et avec la houille grasse à volatilité basse, ce qui forme le plus grand obstacle au développement de l'industrie des briquettes. Par conséquent, la production des briquettes, quoiqu'elle augmente, est encore basse (970.000 tonnes en 1927).

La carbonisation à basse température a donné lieu à un intérêt répandu et beaucoup d'installations ont, en 1927, vendu du coke ou des briquettes fabriquées de houille carbonisée à basse température. La quantité de la production à basse température n'est pas importante. La carbonisation à haute température comme source de combustible domestique est bien établie. La basse teneur en matières volatiles du coke produit à haute température—2 pour cent ou moins—est sans importance pour les fours à chauffage central en usage général aux Etats-Unis, dans lesquels on allume le feu en automne et le fait brûler jusqu'au printemps. A peu près 1.300.000 tonnes de coke d'usine à gaz, distille en vases clos horizontaux, se vendent tous les ans pour des buts domestiques; ses inconvénients sont une friabilité et une mollesse extrême. Un coke de meilleure qualité se produit dans les fours à coke à récupération des sous-produits, et la vente du coke de cette espèce pour des buts domestiques a augmenté de 1.400.000 tonnes en 1918 à 4.700.000 tonnes en 1927. Ce coke, bien criblé à des grosseurs types, s'adapte bien au commerce domestique et se vend à des prix variant entre $5.00 et $10.00 par tonne franco à bord de l'installation. Beaucoup de compagnies du gaz municipales sont en train d'installer des fours à coke à récupération des sous-produits, lesquels produisent un coke de haute valeur et du gaz à petits frais; six de ces installations se sont faites pendant les deux années passées et il y en a encore quatre en construction.

Encore une tentative à la solution de ce problème consiste à employer les houilles grasses à volatilité basse provenant de la région méridionale de la Virginie de l'Ouest et de la région centrale de la Pennsylvanie; ces houilles ont une teneur variant entre 17 et 25 pour cent en matières volatiles et fument très peu en brûlant. Des houilles de grosseurs types, "sans fumée" soi-disant, et de la houille tout venant se vendent à présent pour le chauffage domestique dans beaucoup de villes, en particulier dans la région centrale des Etats-Unis.

L'application du gaz et des huiles est plus répandue, parce que leur emploi élimine les cendres aussi bien que la fumée, tout en permettant un contrôle automatique absolu. L'emploi du gaz fabriqué pour le chauffage domestique n'est plus en état d'expérimentation, et 1.700 domiciles ont ce système de chauffage dans la seule ville de Baltimore. L'huile s'emploie à présent en grandes quantités pour le chauffage et des domiciles et des édifices tels qu'hôtels, appartements, bureaux et institutions publiques. Les appareils brûleurs à huile installés dans les domiciles sont en général tout à fait automatiques et brûlent des huiles d'une pesanteur de 45° jusqu'à 28°. Les appareils installés dans les plus grands bâtiments sont

en général construits pour contrôle à main et emploient des huiles plus lourdes, variant entre 24 et 12 et demandant un chauffage préalable. La consommation d'huiles pour chauffage, en 1927, et pour les maisons et pour les plus grands édifices, s'élevait à 26.350.000 barils (ce qui équivaut 6.500.000 tonnes de houille). De cette quantité, 11.300.000 barils furent consommés dans les Etats septentrionaux bordant l'Atlantique, 450.000 barils dans les Etats méridionaux bordant l'Atlantique, 10.100.000 dans les Etats centraux, et 4.300.000 dans les Etats sur la côte du Pacifique.

THE FUNDAMENTALS OF COAL BLENDING AND THE PRODUCTION OF SOLID SMOKELESS DOMESTIC FUEL

THE JOINT FUEL COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS, THE SOCIETY OF CHEMICAL INDUSTRY, THE COKE OVEN MANAGERS' ASSOCIATION AND THE INSTITUTE OF FUEL

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CONTENTS

The fundamental principle underlying the blending of one coal with another or with a diluent is the modification of the behaviour of the coal during subsequent treatment by carbonisation or combustion.

The earliest reference to the recognition of this principle appears to be in connection with the production of good metallurgical coke; Joseph Souquière, of Paris, taking out a patent (B.P. 1091, 1859) for the blending of powdered coal with powdered coke made from the same coal. Even after this lapse of time Souquière's conclusions still remain true: the coke has an improved appearance, is more dense and is sonorous and firm; the retorting operation is completed in less time and the coke is often discharged in one lump.

The adaptation of the principle to low temperature carbonisation was patented by G. Haycraft in 1895 (B.P. 18,156), his diluents being anthracite as well as coke breeze, and his temperature of carbonisation being below 500°C.

The idea of using a poorly caking coal as the diluent for modifying the swelling of recognised coking coals seems to have become adopted quite widely without very special reference. This is perhaps not surprising when it is remembered that the average coal seam is built up of bands whose properties may vary considerably. Therefore, although good results in coke manufacture would be easily obtainable with uniform seams there is no doubt that with a banded seam the principle of blending first appears as the necessity for intimately mixing these bands. From this consideration to the mixing or blending of dissimilar coals from a number of seams it is only a short step.

Early in this century more direct attention has been turned upon the modification of the behaviour of coal during carbonisation. This has taken the form in part of research upon those constituents of coal which act as binder in the formation of coke and in part of observation of the behaviour of coal during the initial stages of heating prior to coke formation.

Objects of Blending

Before detailing these researches it is necessary first to consider the objects of blending. The main object has been the production of coke of a type suitable for certain purposes. For metallurgical purposes toughness, uniformity and high density are of greatest importance, with "reactivity" problematic. For the production of smokeless fuel ready combustibility is of the greatest importance, toughness is necessary only to an extent, and a high density, though desirable also to an extent, is not essential.

To this object has now been added that of increasing the general efficiency of the process, the increase being manifested in any of the following ways:

(1) The increased yield of some product such as gas or tar.

(2) The improvement in the quality of one or more products such as coke.

(3) The modification of the properties of the coke in respect to uniformity, hardness, density, or combustibility.

(4) The increase in output from a given plant and therefore of the thermal economy of the process.

(5) The utilisation of a type of coal not so far suitable for the purpose.

(6) The conversion of a material of low value such as coke breeze into saleable coke of higher value.

The relative importance of these ways is not altogether clear, but the greatest light on the problem has come from a study of the mode of formation of the coke, and of the escape of the volatile products from the heated coal mass, and of the structure of the coke itself. In addition, the process offers distinct promise of fuel conservation.

EFFECT OF HEAT ON COAL

If a coal of the type used in coke manufacture be heated sufficiently slowly the removal of the volatile products is sensibly a process of distillation. Burgess and Wheeler[1] have shown that an appreciable evolution of liquid volatile products begins at 280°C. As the liquid distillate is removed with the minimum of decomposition of the constituents which form the cementing medium for the coke, it is to be expected that the coke resulting from slow heating would be of relatively weak structure. This type of coke possesses the property of high reactivity or combustibility, while coke formed under the conditions of high-temperature carbonisation (in gas retorts or coke ovens) is not reactive in this sense, owing to the more rapid rate of heating and to secondary decomposition on the coke of the volatile products. If this be accepted, the explanation of increased combustibility must be looked for in part in a modification of either structure or surface, as residual volatile matter does not, as will be shown later, account fully for the difference.

Taking an example from coke-oven practice, we have an explanation in the work of Foxwell,[2] and Ryan[3] for what takes place when coal is suddenly subjected to a high temperature. The coal layer next the retort wall is heated rapidly and becomes plastic or molten. As the heat penetrates the charge this plasticity extends towards the centre. Decomposition follows as the temperature rises, and the plastic mass becomes a hard cellular residue. The process may, therefore, be visualised as the travel of a zone of plasticity from the heating surface to the centre, which leaves behind a coke whose structure depends upon the coal and the conditions of heating. The researches of Foxwell and Ryan have determined that the rate of travel of this zone is the controlling factor in the speed of carbonisation of coal. The thermal conductivity of the plastic zone should not be less than that of the coal, and the thermal changes in its decomposition are relatively small so that, as was at first supposed, the zone itself is not a bar to the transfer of heat. So far as the passage of gases, etc., is concerned the zone is relatively impermeable and in the initial stages of heating the volatile products must be driven inwards and either escape through the unheated

coal or be condensed upon it. Later, an increasing proportion passes through the hot coke and suffers severe thermal decomposition upon it. Foxwell[2] in an experiment upon the resistance to gas flow of "plastic" coal has calculated that in a 16-in. coke oven all the gases are passing through the coal for over 9 hours, and that after 20 hours only about 20 per cent. are passing. It is this drastic secondary decomposition of volatile products upon coke which gives oven coke its characteristic appearance.

COKE STRUCTURE

Sir G. Beilby,[4] in a careful microscopical examination of the structure of cokes, traced the formation of bubbles in the plastic mass, which by contact and the blowing of smaller bubbles in their walls, produced what he termed "a bubble sponge" structure. He also demonstrated the continuity of such structure in normal cokes and in briquetted blends made in the manner described by Sutcliffe and Evans.[5] On the assumption that the maximum of reactive surface is desirable in a "combustible" coke he specified the most desirable structure as "the subdivision of the carbon mass into films of minimum thickness separated by spaces of equal width." He claimed that this ideal can be most nearly approached by fine grinding and careful blending to give small cells and thin walls. That this is only a partial explanation is shown by the fact that it is possible to produce by low-temperature carbonisation a "reactive" coke having relatively large pores.

Nevertheless, the question of producing maximum surface in coke is of the greatest importance, and it is here that blending becomes necessary with fusible coals to reduce the effect of the plastic zone, to allow more distillation in the initial stages of heating and to produce a coke which may be dense but is permeable in all its stages, and which finally retains a small bubble structure.

The nature of the surface of the cells and walls must, however, also be of importance. Parker[6] has endeavoured to follow up this point by examining the structure of a series of cokes placed in a definite order of reactivity. He finds that with increasing reactivity he has increasing uniformity of structure, and an increase in the number of small pores appearing in the walls of the larger cells. The phenomenon of cenosphere formation pointed out by Newall & Sinnatt[7] should constitute a promising method of studying this problem. The perfect cenospheres formed under correct conditions by fusion of coal particles become smaller as the coal is blended with inert material, and eventually

form aggregates which consist of large numbers of very small cenospheres fused together.[8] The inert material used was electrode carbon, which is unlikely to be a good absorbent for the binder, but it is nevertheless apparent that there must be some connection between such aggregates and the ultimate "bubble sponge" structure referred to above by Bielby.

In the work on reactivity of coke which is proceeding at the Fuel Research Station it has been observed as a generalisation that the cokes with thick strong cell walls are those which show low reactivity to carbon dioxide. Measurements of the relation between the size of the main cells and wall thickness show that this ratio alone has no bearing on reactivity.

	Apparent specific gravity.	Ratio: $\frac{\text{Cells.}}{\text{Total.}}$
Sugar coke, high reactivity.. ..	0·89	0·57
Vertical gas-retort coke	0·70	0·71
Oven coke from blend, low reactivity	0·88	0·55

This, taken in conjunction with Parker's conclusion, emphasises the need for further study of the effect of nature of surface as distinct from uniformity of structure. Discrimination between these two effects is complicated by the effect of inorganic constituents.

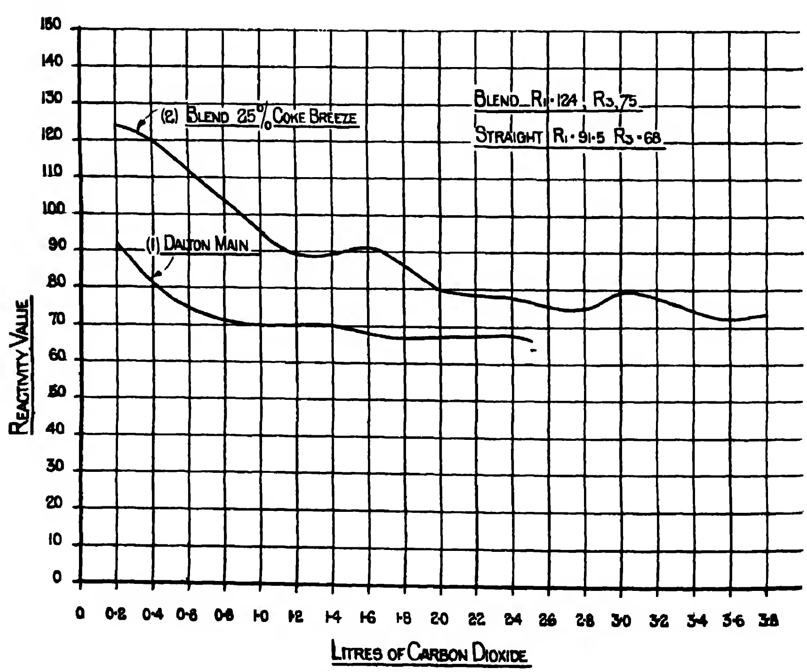


Fig. 1. Comparative Reactivites of Straight and Blended Cokes.

Several workers have demonstrated remarkable increases in reactivity owing to the presence of such substances as sodium carbonate. The effect of blending on increasing the reactivity of coke to carbon dioxide is shown in Fig. 1, where curves obtained by the method of Jones, King and Sinnatt[9] are shown for two horizontal retort cokes; (1) from coal alone, and (2) from a blend of the same coal and coke. This effect may be assumed to combine those of improved structure and more reactive surface. It is also possible that the molecular structure of the carbon may affect reactivity. Terres and Biederdeck[10] have shown that the specific heats of carbon fall into line with that of graphite if the carbon is heated in the region of 1020° to 1150°C. Such changes may well affect reactivity also, and account in part for the low values associated with highly overheated cokes.

THE BINDER AND THE DILUENT IN COAL BLENDS

For any given system of carbonisation it is conceivable that one coal seam may contain just the right amount of the binding constituent to give a good coke of high density and even structure. Such seams are rare and it has been normal practice in the past to employ for coke manufacture coals containing an excessively high proportion of the binding constituent, the necessary density being attained by the confining action of the retort walls.

By means of blending it is possible so to arrange the proportions of the blend to suit carbonising conditions that the binder present is just sufficient to give a strong hard coke. The secondary considerations of increased rate of heating and reactivity of product will then follow, the former, of course, having its effect also on the formation of the coke.

The determination of the binding constituent in coal has been the subject of considerable research. Wheeler, Illingworth, and others have found that that portion of the coal soluble in pyridine and chloroform—the gamma (γ) compounds—is largely responsible for the formation or otherwise of a strong coke from bituminous coal. Similarly, Bone[11] and Fischer[12] and their co-workers have separated, by the extraction of coal with benzene under pressure, about 8 per cent. of extract. This extract they separate, Fisher into two, and Bone into four constituents by fractional solubility in petroleum ether and alcohol. Fischer's constituents are an "oily" fraction soluble in petroleum ether, to which he attributes cementing properties in coke manufacture, and a waxy "solid" residue to which he attributes the swelling of coal during carbonisation. Bone's

four fractions are obtained by further treatment of the "oily" bitumen with light petroleum, and the "solid" bitumen with ethyl alcohol.

The correlation of these different principles to which the caking of coal is attributed is a matter of some difficulty. Cockram and Wheeler[13] have, while separating their gamma compounds into four fractions (γ^1 to γ^4) compared the results with those of pressure-benzene extraction by both Fischer's and Bone's methods. They point out that Fischer's method is not truly applicable to British coals on account of decomposition starting at well below the temperature of 285°C.[14] employed, and show that Bone's fraction IV. consists of at least two constituents.

Speaking generally, therefore, it does not appear desirable at the moment to consider the ability of a coal to form a strong coke in terms of the percentage of "caking constituent" as determined by any of the above conventions. A more simple basis for consideration is to assume that caking coals contain binders which vary not only in quantity but in their behaviour on carbonisation. The remainder of the coal or added material in a blend may then be considered as a "diluent" whose effect will vary with size of particle and capacity for absorbing the binder.

As regards the behaviour of the binder on heating, Parr and his associates[15] were the first to point out that not only must the binder be present in the correct proportion but it must not decompose below its melting point in order to allow of good penetration of the liquid phase before decomposition. The melting point of the binder is, therefore, of primary importance. It has been shown by several workers that the values for good coking coals lie between 370° and 500°C. and that the range of plasticity is from 50°–100°C. The behaviour of coal on slow heating and the part played by fusion has been clearly demonstrated in small-scale experiments by Charpy and Durand[16] and Audibert[17]. The first action on heating is a progressive contraction in volume of as much as 33 per cent. to the point where fusion takes place. The volume increases again on further heating to an extent which may be very large owing to bubble formation. When this is completed the final contraction characteristic of coke formation takes place. Coals in which the melting point is preceded by decomposition show only partial fusions, but the temperature of fusion and its extent may be increased by increasing the rate of heating. Such coals are shown to give good cokes if preheated for a period at a temperature just above the softening point and then heated rapidly to a high temperature.

This phenomenon is the subject of a patent by Illingworth (B.P. 187,328, 1921).

The application of these observations to the production of coke by blending may now be summarised.

(i) In coals whose melting point is below their decomposition point all that is necessary is dissemination of the binder to a sufficient extent.

(ii) In the second type of coal either greater rapidity of heating or preheating will produce a strong coke.

(iii) The increased rate of transference of heat made possible by blending will bring within the coking scale coals not hitherto used.

A B. C.

Fig. 2. Control of Blending by the Gray-King assay.
A. Intumescent coke from strongly-caking coal.
B. Pulverulent coke from weakly-caking coal.
C. Strong hard coke from blend of A and B.
Scale.—Two-thirds full size.

If to these be added the practical observation that long exposure to a high temperature increases the specific gravity of a coke, and decreases its combustibility, it is realised that the rapid heating ensured by blending will, if assisted by proper sizing, give a coke which is both readily combustible and reasonably dense.

At the moment the methods of Wheeler, Bone and certain others do not seem practicable ones for the control of blending, but a possibility does exist that the determination of melting point and decomposition point of a coal or proposed blend might be a good method of control. Otherwise it would seem necessary either to rely upon trial in the retorts—the ultimate test—or make use of a laboratory carbonisation test, such as the Gray-King assay recommended by Sir G. Beilby.[4] Fig. 2 represents three cokes made in this apparatus, (*a*) intumescent coke from a strongly-caking coal, (*b*) pulverulent coke from a weakly-caking coal, and (*c*) strong hard coke from a blend of the two. In using such an apparatus it is only necessary to correlate in a few instances the appearance of the coke with that obtained from the same coal in the plant.

THE EFFECT OF PARTICLE SIZE, ETC.

It might appear from the above that the most uniform coke would result from the most intimate mixture of binder and diluent, and that these constituents should be finely divided. As this is not necessarily practicable it is interesting to consider whether the caking constituent—the cement in the aggregate—should be finely disseminated or whether the non-caking constituent—the diluent—should be. As the coke produced from lump non-caking coal is weak, it is probable that unless this constituent be finely divided lines of weakness would result within these lumps, and that the lumps themselves would be friable, and produce an undue amount of dust. On the other hand, if the diluent be finely divided it cannot have the same effect on the plastic zone, each lump of fusible coal forming a region of large bubble structure.

Experiments in this connection[18] are of interest in which blended charges for a horizontal gas retort were prepared. In the first blend the caking constituent was in the form of nuts and the other in the form of dust less than $\frac{1}{8}$ in. In the second blend the reverse was the case. To complete the series two further charges were also carbonised, the first of a mixture of nuts and the second of a mixture of finely crushed coals (below $\frac{1}{4}$ in.).

In each case the coke was dry-cooled and examined as to its size and crushing strength. For the sake of comparison the results are

shown in the following table in comparison with those of a coke made in the normal manner from the caking coal, which was a normal gas coal.

MIXTURES OF EQUAL PARTS CAKING AND NON-CAKING COALS USING DIFFERENT SIZES OF PARTICLE.

	1.	2.	3.	4.	5.
Type of caking coal.. ..	nuts	nuts	fine	fine	nuts
,, ,, non-caking coal ..	nuts	fine	nuts	fine	nil
Screen analysis—					
Over 2 in.	44·1	53·5	68·1	80·7	73·4
2 in. to ⅞ in.	33·0	24·9	23·1	11·4	18·9
Below ⅞ in.	12·9	19·6	8·8	7·9	7·7
Shatter test—					
Over 2 in.	42·3	44·1	59·7	76·5	65·0
2 in. to 1 in.	38·6	40·5	29·0	15·0	25·5
Below 1 in.	19·1	15·4	11·3	8·5	9·5

From the point of view of appearance alone the best coke was No. 4, though No. 5 was almost as good.

No. 4 is again the best so far as the production of large or strong coke is concerned, but the fact that No. 3 is almost as good as No. 5 is an indication that the important point in coal blending is the fineness of division of the caking constituent.

It is well known that the strength of a coke is increased by the fineness of grinding of the coal used. T. Biddulph Smith[14] quotes crushing strengths of 212 and 1003 lb. per sq. in. for the same coal sized from 1 in. to 1/30 in. and below 1/90 in. respectively. In a blend, however, the non-caking constituent may be in relatively large pieces as it may have the property of absorbing sufficient binder to overcome the natural weakness of coke from such coals.

This conclusion is not altogether borne out by reference to the literature. As long ago as 1850 J. P. Budd (B.P. 13,121) patented the formation of coke from coal blends, claiming that it was of chief importance that the non-caking constituent be finely divided. An explanation of this discrepancy may lie in the fact that the absorptive capacity of non-caking coals may vary.

Audibert[20] has demonstrated by microscopic examination of fused blends that certain coals form complete fusions with one another while others form only agglomerates in which there is more than one solid phase (see page 21).

Recently Krönig[21] has investigated on a 20-gm. scale the effect of size of coal and of diluent on the density of the resulting coke. His conclusions are that

(1) For swelling coals the density of the coke increases with fineness of particle.
(2) For each coal there is an optimum rate of heating depending upon its swelling power and an optimum amount of diluent.
(3) The absorptive capacity of the diluent is of greater importance than its density, and even low-temperature cokes can be increased in density from 0·7 to 0·9 by blending with semi-coke.

Similarly, Kreulen [22] has examined the effect of variation of particle size of the diluent (sand and graphite), classifying the resultant cokes by their resistance to impact. He also finds that the strength of the coke increases with decreasing particle size of the diluent and reaches a maximum with addition of about equal total surfaces of added material and coal. In an investigation on the addition to caking coal of a non-caking coal of varying size of particle he confirms the fact that if a definite proportion of coals yield a coke of the required strength the proportion of diluent can be increased without affecting strength, if its particle size be reduced.

From this evidence it may, therefore, be concluded that the strongest cokes are obtained by fine grinding of the diluent, but that this diluent need not be finely divided if it is capable of absorbing the binder of the other coal. If finely divided a non-absorbing diluent may be added in higher proportions.

The disadvantages of fine grinding for both constituents are apparent; first, the cost of such grinding, secondly, the difficulty of obtaining an intimate mixture, and thirdly, the reduction in rate of heating owing to the restriction of convection by the finer particles of coal. The effect of particle size on rate of heating has become realised lately with particular reference to continuous vertical gas retorts, and in several installations considerable increases in throughput have been achieved by operating with sized coals[18].

A. Parker[6] in tests on sized coal in a small-scale horizontal retort has shown a steady increase in rate of gas making as the size of the coal is increased from 10–30 mesh to $1\frac{1}{4}$ to $\frac{3}{4}$ in coal. The total yield of gas in both cases is much the same, but in gas making practice the rate of arriving at a certain stage is the important point. Parker points out the slowing effect of mixtures of sizes owing to the blanketing action of the fine dust. Therefore, although experimental evidence on this point is limited, it may well be that in the carbonisation of blends, it is of advantage to retain the non-caking coal in relatively larger particle size. This may not be true

if the diluent is coke, as coke is less likely to exert so strong an absorptive action on the binder.

Fine grinding has, however, an advantage of some importance in assisting in the production of coke of high density. In a coal blend in which the constituents are correctly balanced to prevent swelling, and reduced to such a size of particle that the percentage of voids is a minimum, the most dense type of coke should result. By high-temperature carbonisation such a coke, if strong and hard, would be particularly valuable for metallurgical purposes; in low-temperature carbonisation it would tend to reduce one fault of modern smokeless fuels—low bulk density.

Sutcliffe and E. C. Evans[5] achieved high density by first pulverising the coal and then compressing it into a briquette before carbonisation. In such a process intimacy of mixing and the ensuring of a fine bubble structure is combined with the large particle (briquette) size which will ensure rapid carbonisation. E. V. Evans[23] has followed up these pioneers by carbonising in horizontal gas retorts blends of gas coal with fine coke breeze. The combined effect of blending and increase of particle size resulted, in Evans' experiments, in the reduction of the period of carbonisation from the normal of 9½ hours to 6½ hours. Briquettes made by the Sutcliffe, E. C. Evans process may have an apparent specific gravity as high as 1·30; the coke made by E. V. Evans having a value in the neighbourhood of 1·05.

An experiment[18] in which a blend of gas coal and non-caking coal (60 : 40) was crushed to such a size of particle as to have approximately minimum voids and carbonised in a horizontal gas retort showed that, with suitable blending from the point of view of both binder and size of particle, the coke was noticeably harder and more uniform than coke made in the same retorts from the gas coal alone. The expected increase in density was not obtained, probably owing to the lack of internal pressure during carbonisation.

	Gas coal. Nuts.	Blend. Min. voids.
Size :—		
Over 2 in.	73·4	73·1
2 in. to ⅞ in.	18·9	13·1
Below ⅞ in...	7·7	13·8
Shatter Test :—		
Over 2 in.	65·5	72·1
2 ins. to 1 in.	25·5	18·5
Below 2 in...	9·5	9·4
Apparent specific gravity of 2 in. cube	1·02	1·00

Briquetting is, therefore, a promising method of combining fine grinding with blending while retaining a large size of particle, but

it is unlikely that its full value will be realised until economic conditions make it possible for the industry to stand this additional charge. As pointed out by E. V. Evans[23], the economic production of blended briquettes would probably establish definitely in the gas-making world the supremacy of the vertical retort for this purpose.

Blends of Caking and Non-Caking Coals

It may be concluded from the above considerations of size of particle that the most satisfactory coke is obtained when all the constituents of the blend are finely divided. Apart from efficient mixing, the important consideration is the arrangement of these constituents to give a sufficiently strong and dense coke.

Reference has been made to the work of Charpy and Audibert, indicating that certain coals may be specially suitable as diluents owing to their absorptive capacity for binder. Audibert[20] has shown by microscopical examination of sections of coke made from blended coals that a proper choice of coals will yield a single solid phase on cooling, while with two unsuitable coals two solid phases are obtained, embedded in a matrix which has solidified after fusion. Audibert therefore, visualises the careful choice of coals for blending using this convention. His method of choice is the determination of the softening point of each coal and of the blend. In one example quoted the addition of only 5 per cent. of one coal reduces the softening point of the mixture to 40°C. below that of the other constituent, and ensures complete fusion of both well below the decomposition point. This is an important observation so far as the production of strong oven coke is concerned, and laboratory control on these lines should well repay its cost, the aim of the blender being the production in the oven of a uniform and complete fusion.

Such careful work would be necessary only when dealing with new coals ; where regular supplies of known coals were being used more simple tests would be sufficient for control when coupled with observation of the coke produced. The blending of bituminous coals on a large scale has now proceeded far beyond the experimental stage and in many large coke-oven plants blending of relatively large numbers of seams is now common practice. After the initial choice of coals and proportions the control necessary to produce a uniform coke is reducible to a simple test such as the percentage of volatile matter or the caking index (Campredon or Meurice). D Brownlie[24] gives details of manufacturing practice in America and on the Continent which are of general interest in indicating

the precautions necessary in sizing, cleaning, and blending of a relatively large number of constituent coals. The same methods could well be applied to gas manufacture, with the reservation that a richer blend is necessary for slower heating or for processes in which the coal is in motion during carbonisation, unless artificial sizing such as briquetting is employed.

A number of blending patents have been taken out within recent years for various modifications of technique. The most important are those of J. Roberts and S. R. Illingworth. Roberts' first patent[25] stipulated that the proportions of the blend should be such that the diluent coal should utilise any excess of binding material in the other coal and prevent undue expansion. From finely crushed coal (less than 1/10 in.) a strong hard coke could then be produced by carbonisation at 600–760°C. Coke breeze was quoted as an alternative diluent to be used in partial substitution for non-caking coals of specified volatile contents. Later this patent was amplified to stipulate the mixing of equal parts of coal containing 7·5 per cent. and 6·5 per cent. respectively of substances soluble in pyridine and chloroform (the γ compounds of Wheeler).

S. R. Illingworth[26] has based several patents upon his researches on the gamma compounds in coal. The first was not based on blending but on the preheating of non-caking coals to 550°C. to destroy non-coke-producing substances but leaving 5 per cent. of resinic substances for the production of coke at higher temperatures. Later he stipulated the blending of coals to a resinic content of 5 to 8 per cent., and their carbonisation for the production of smokeless fuel at 50°–100°C. above the decomposition temperature of the resinic matter.

Since this time the use of blending for the production of smokeless fuels has been strongly advocated by Roberts, and a certain amount of experimental work has been carried out both for this purpose and for the production of metallurgical coke.

H. H. Thomas[27] in an experiment on a 1/1000th ton scale has shown that a hard coke of even structure is obtainable from a 70/30 blend of caking and non-caking coals. The gaseous thermal yield was the same as that obtained from the two coals separately, and the rate of carbonisation was slightly greater, as measured by rate of gas evolution. This increase in rate was small in comparison with that obtained by using coke as the diluent. Any effect such as this is obscured by the effect of the size of the coal particles, and in the present state of our knowledge it does not appear definite

whether the size effect is greater in this respect than that of modification of the plastic layer. In Thomas' experiments the effect of size reduction from 1 in. to $\frac{3}{4}$ in. to $\frac{3}{8}$ in. to $\frac{1}{8}$ in on time of carbonisation was a 16 per cent saving, an indication that size is the more important factor. This is in accord with a statement by G. Weyman[28] that the rate of gas evolution in a blend depends upon the size of the material before charging.

Further experiments on blending as a means of improving the quality of gasworks coke are described by H. Hollings.[29] In this case increases in throughput of 30 to 40 per cent. were obtained by carbonising blended pitch-bound briquettes in vertical retorts. Here also it is difficult to differentiate between the effects of size and blending.

These experiments were conducted in consequence of work done by the Woodall-Duckham Company and quoted by E. W. Smith[30] in a paper on the Co-ordination of Fuel Supplies. This work briefly demonstrated the production from blends of coal and of coal and coke dust of free-burning coke, and the saving of one-third of the normal coking time. The net cost of preparation of briquettes strong enough for charging to Woodall-Duckham vertical retorts is given as 2s. 5d. per ton. Against this may be placed the gain in throughput of 40 to 50 per cent., the obtaining of a better thermal yield from the coal owing to the free passage of gas, and the production of combustible coke.

F. Bönnemann[31] describes how careful control of carbonising conditions has improved the coke from certain Silesian coals, and allowed his Company to dispense with the necessity for purchase of other coals, and to economise in the amount of fusible coal necessary. His final conditions combine blending with grinding to less than 4 mm. size, the use of narrower ovens and higher temperatures for more rapid heating. The homogeneous structure of "blended" coke is again referred to and it is stated that complete fusion of the constituents of the blend is achieved. The best diluent used by Bönnemann was partially carbonised coal containing not less than 17 per cent. volatile matter. The practical value of these experiments is shown by the fact that some 1200 tons of the blend when tested in a blast furnace gave higher efficiencies and a better quality of pig iron.

COAL AND ANTHRACITE OR SEMI-COKE

If anthracite or semi-coke be taken as the diluting constituent of a blend in place of non-caking coal the possibility of a difference in

behaviour during carbonisation is at once evident. Anthracite does not decompose on heating until over 500°C., when decomposition of the resinic matter in the caking coal is well advanced, while semi-coke does not begin to give off gas until about 600°C. The spreading of the binder through the mass should therefore be facilitated. The liberation of hydrogen in the later stages of carbonisation would also tend to reduce the amount of cracking of hydrocarbons and to produce a more reactive coke. The moderating effect on the plastic layer would be as great, as this is mainly a function of the surface available, but the true cementing action occasioned by absorption of the binder may not be so evident as with many non-caking coals. Anthracite as a diluent has been used from the earliest times, owing to the obvious availability and apparent uselessness of anthracite duff. The blends produced are strong and hard, but tend to produce dust on breaking owing to separation of the loosely bound particles of anthracite. The Strafford process [B.P. 176,822 (1922) and 221,526 (1924)] is of special interest in regard to anthracite. Certain constituents of the blend are pulverised and mixed with the aid of an emulsion of soft soap or creosote. On carbonisation in a coke oven the product is of extremely uniform texture and is very dense and hard. Despite this high density it is highly reactive, and it is claimed that it can be ignited readily in domestic fireplaces.

Semi-coke on the other hand, while it may not absorb the binder into the coked material as readily as coal, does absorb it into the cell structure and, by point cementation at least, tends to form a continuous homogenous structure with the semi-coke as a framework. As the liberation of gas from the semi-coke does not take place until after the distribution of the binder it is unlikely that it has any weakening effect on the structure. The work of Bönnemann[31] is of special interest in this connection. Where semi-coke is used as a constituent of a coal blend for the manufacture of metallurgical coke he states that the best coke is obtained if the volatile matter in the semi-coke is not reduced below 17–19 per cent. The advantage of semi-coke of this type may well be its greater ability to absorb the binder in comparison with the more inert cokes formed by stronger heating and containing only 1–2 per cent. of residual volatile matter.

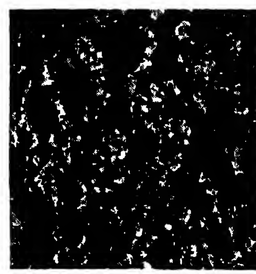
The economic aspect of the use of semi-coke is not so clear. Where breeze is available from a smokeless-fuel plant or waste heat can be employed for preheating, the question does not arise, but it does not seem an economic possibility to produce semi-coke for this purpose. Anthracite duff, on the other hand, while less suitable, is in certain

districts not only available and cheap but a material whose proper utilisation is a matter of some difficulty.

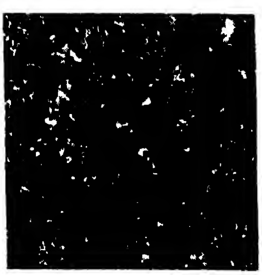
Fig. 3. Photomicographs of cokes (× 10).

A. Coal-coke blend.

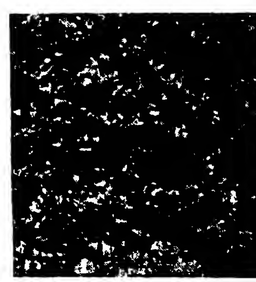
B. Horizontal Gas Retort.



C. Vertical Retort.

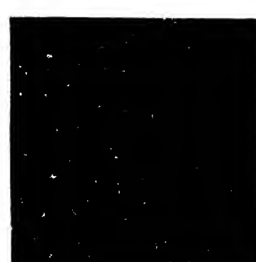


D. Metallurgical from coking coal.



E. Metallurgical from blend.

F Hor'zontal Gas Retort blend.



G. Sugar—sugarcoke blend.

COAL AND COKE

The action of coke in a blend with caking coal can only be dilution or spreading of the caking constituent or binder. The small particles of coke are not likely to be appreciably altered by absorption of binder, but serve as a matrix round which the final coke structure is built up. Such structure may well be sufficiently porous to prevent the formation of a plastic zone and to allow free distillation of the richer gases in the early stages. The resulting coke is, therefore, subjected to a less extent to the cracking upon it of these hydrocarbons, and has not the metallic lustre and low reactivity associated with high-temperature cokes. Its evenness of structure is now well known, and is illustrated in Fig. 3, *A* in comparison with ordinary gasworks coke *B* and *C*, and metallurgical cokes *D* and *E*. That this uniformity of structure is the inevitable result of blending with coke may be shown by taking the extreme case of sugar carbonisation. Sugar, as is well known, froths excessively on heating to produce finally a very light carbonaceous mass. If this mass be powdered and mixed with one-third of its volume of sugar a dense hard coke can be produced. Fig. 3*G* shows a section of such a coke of which the apparent density is 0·88. Fig. 3*F* represents a coke made from a blend of gas coal and non-caking coal in a horizontal gas retort. The structure is more uniform than that of coke made from gas coal alone *B* but is not quite so good as that of the coal-coke blend *A*.

The apparent density of coal and coke blends is lower than that of metallurgical coke owing to this regular porosity, but Sutcliffe and Evans[5] and E. V. Evans[23] have shown that cokes of high density can be produced from blends which have been carefully blended and agglomerated by pressure prior to carbonisation. Some of these values are quoted below :—

		Apparent specific gravity.
1.	Low-temperature coke, F.R.S.	0·65
2.	Sugar coke, F.R.S.	0·88
	Gas retort cokes :—F.R.S.	
3.	*Vertical retort	0·70
4.	*Horizontal retort normal	1·02
5.	,, from coal/coke blend	0·72
6.	,, from "minimum voids" blend	1·00
7.	Horizontal retort, blended briquettes	1·05
8.	Sutcliffe-Speakman briquette (anthracite)	1·30
	Metallurgical cokes.	
9.	*Yorkshire	1·02
10.	S. Wales blend	0·89
11.	Yorkshire non-caking (lump coal)	1·29
12.	S. Wales Foundry	0·89
13.	Strafford anthracite blend	1·30

*From same coal.

The criticism which may be levelled against the use of coke for this purpose is that it occupies space in the retorts without contributing to the gas or tar or to the output of the operation. This criticism holds if the same object can be achieved by the use of a non-caking coal. So far as the production of a strong dense coke is concerned this is true, but it does not seem to be established that the coke from blended coals is as readily combustible as that from coal-coke blends. This is an important point so far as the production of a suitable domestic fuel for open grates is concerned, and may discount the relative loss of output.

Against this apparent loss of capacity of the plant may be balanced the gain in throughput possible owing to the increased rate of carbonisation. This increase of rate is due in part to modification of the plastic zone and in part to the higher thermal conductivity of coke over coal. J. Roberts[32] in small-scale experiments on the transmission of heat into blends indicates decreases in time of heating to a given temperature of as much as 50 per cent. by blending a fusible coal with its own weight of coke breeze. E. V. Evans[23] has also demonstrated a reduction in carbonising time from 9 to 6½ hours, although this reduction is also complicated with the effect of size. Other authors have made the same observation. Even if this reduction in time is not sufficient to maintain the gaseous thermal output of a given plant the loss might be fully compensated for by its provision of a means of utilising coke breeze, and the possibility of the sale of the whole output of coke at an enhanced value.

It might be supposed that the action of coke in limiting the fusion zone and giving a free access of volatile matter would result in lower gas and higher tar yields. The only results which seem to be available on this point are from E. V. Evans' experiments[23] on the carbonisation of a briquetted blend in horizontal gas retorts. In these experiments it was not possible to put "the quantity of heat required to effect the degree of cracking necessary to give the enhanced yield of gas" through the retort walls. Nevertheless, the total volatile therms show the remarkable increase of about 8 therms, the tar yield being almost doubled.

	Durham coal.	75/25 coal/coke briquettes.	
		A.	B.
Therms per ton of coal.			
Gaseous	74·7	68·2	71·1
Tar	16·1	31·0	27·5
Total	90·8	99·2	98·6
Increase in total . ..	—	8·4	7·8

The experiments of Krönig[21] on the use of semi-coke apply also to the use of other cokes with the provision that, as Krönig states, the absorptive capacity of the diluent is of greater importance than its density. This provision would seem to indicate that high-temperature cokes would have a less strong diluting action owing to less absorption but would tend to give weaker cokes.

So far as the yield of gas only is concerned some information is obtainable from small-scale (1/1000th ton) experiments carried out by H. H. Thomas.[27] After emphasising the need for fine grinding and intimate mixing he shows that the addition of coke gives an increased yield of gas of lower calorific value but without loss of thermal yield. This is, perhaps, contrary to the above result of E. V. Evans' experiments, but the difference is probably due to the fact that Thomas continued his heating to exhaustion of the charge.

SOLID SMOKELESS FUEL

The trend of modern endeavour in this country towards the production of solid smokeless fuels has been mainly in the direction of providing a satisfactory fuel to replace the 40 million tons of coal at present being consumed in domestic appliances. The necessity for this is partly the alleviation of the smoke nuisance, to which the domestic fire is, perhaps, the main contributor, and partly to prevent the loss of by-products involved.

Industrial smokeless fuels are less necessary owing to the general adoption of more efficient methods of combustion and to the adaptation of furnace grates to suit smokeless fuels such as gasworks coke.

The first step in the substitution of raw coal for domestic purposes is obviously the production of a fuel which will give the desired results in appliances intended for the combustion of coal. This does not deny the presence of research, in the opposite direction, on the evolution of a type of grate which will burn efficiently such comparatively incombustible material as gasworks coke. While this side of the problem must continue to be attacked with advantage it is nevertheless necessary that the new fuel give satisfaction in the modern grate.

In this country there are three types of domestic appliance to be considered, the kitchen range, the open fire, and the hot-water boiler. To these may even be added the larger boiler for central heating.

Low-temperature carbonisation processes have already provided a material which gives excellent results in the open grate, and an increase of radiating efficiency over coal. In the domestic range the absence of flame during combustion makes it unsatisfactory for

oven heating, except in those types of grate in which the oven flue is underneath, and the air supply is drawn through the fuel bed only. For hot-water boilers or central heating the only precaution necessary for efficient use is the provision of absolute control of the air supply. The lower apparent density of cokes is a drawback for central-heating installations, but for the smaller water-heaters this drawback is more than offset by ease of ignition.

A partial solution of the problem may lie in the modification of gasworks practice to produce a coke which, while sufficiently strong and hard, would have the property of ready combustibility associated with semi-cokes. It has been shown above that the modification of the fusion zone in coal and the maintenance of an open structure during carbonisation is possible by careful blending of caking coals with non-caking coal, anthracite, or coke, and that the carbonised blend has the structure associated with semi-cokes.

A very good review of the factors governing the utilisation of this process for the production of smokeless fuels, with special reference to modifications which may be adopted, has been given in the winning paper by E. W. Smith and his collaborators[33] in the Coke Competition organised by the *Gas Journal* in 1925.

Several investigators, in particular J. Roberts, have demonstrated the superior combustibility of this type of coke to normal gasworks coke, but experimental evidence is still somewhat lacking in a quantitative sense.

Fishenden[34] has shown that in three common types of open grate low-temperature coke shows an increase of efficiency of radiation over coal of 15, 23 and 27 per cent. Bligh and Hodsman[35], using a special grate in which to burn gasworks cokes, have shown these to possess the same advantage over coal. In this grate the strong draught conditions were unsuitable for low-temperature coke and it did not compare favourably with vertical retort coke. It may therefore be assumed that high radiation efficiency will be realised also with "blended" cokes, and also that the difficulties of poor ignition and the necessity for strong draught will not arise.

In Great Britain some 18 million tons of coal are consumed annually for gas manufacture. From this it may be assumed that less than 10 million tons of coke are available for sale, a quantity which represents only one-quarter of the domestic market. This consideration, and the fact that much of this coke is already very suitable for stoves, is a clear indication that the gas industry could, as at present constituted, supply only a very small portion

of the domestic market. Any increase to meet the demands of this market would only result in the over production of gas.

There is, nevertheless, considerable scope for rendering assistance to the campaign against smoke in making available for general domestic use as much of our gasworks coke as possible. Two obvious advantages to the producer are a more ready sale and the consumption of all coke breeze now being sold at relatively low prices.

Effect on Carbonisation Practice

The necessity for fine grinding and intimate mixing of the constituents of the blend mean that static carbonisation only is possible unless sizing after blending could be made a commercial proposition. In that case it is probable that greater advantages would accrue to flow systems by allowing of considerably increased throughputs of briquetted blends.

Some doubt exists as to the desirability of leaving fairly high percentages (6 to 8) of residual volatile matter in order to ensure ready combustibility. If it be assumed for the moment that this is desirable, the following are considerations for and against the application of gas-making technique to the production of smokeless fuel.

Against.

(1) Cost of crushing and blending.
(2) Reduction in yield of gas per ton of coal.
(3) Handling of greater quantity of coal and coke for the same output of gas.
(4) Non-availability of all constituents for blending.

For.

(1) Utilisation of all coke breeze made in the station.
(2) Increase in yield of gas per retort.
(3) Increase in calorific value of gas.
(4) Increase in monetary value of coke.
(5) Assistance in smoke-prevention campaign.

Cost of Crushing and Blending

It has been quoted that the cost of crushing of coal for coke-oven practice is of the order of 0·48d. per ton of coal, so that it may safely be stated that the combined cost of crushing and blending should be more than compensated for by the elimination of breeze of low market value.

Output of Plant

On a basis of gaseous thermal output, E. V. Evans and others have shown that, while the yield per ton of coal is less, the yield

per unit of plant is actually greater owing to the increased rate of heating. If the coke be discharged earlier in order to leave 7 per cent. of volatile matter in it a reduction of the time of carbonisation of almost half is rendered possible. Under such conditions the yield of gas is more than half the yield under normal conditions, and its calorific value is higher: the latter factor may also be of importance.

If carbonisation be continued to the usual stage of low volatile coke the full yield of gas is obtained in a less time. Thomas has shown a time reduction of 16 per cent. and Evans of 28 per cent. for the same thermal output. If coals only are being blended the balance in favour of blending is, therefore, very apparent when throughput is considered. If coke breeze is used the advantage is less apparent as the coke is obviously non-productive in a gas-making sense. Evans has, however, shown that the throughput of *coal* is not decreased by the use of coke, a 25 per cent. reduction in time of carbonisation being realised with a 20 per cent. coke blend.

T. C. Finlayson[36] in stressing the importance of flexibility in gas manufacture shows how it is proposed to ensure this, together with higher efficiency, by separating gas coals into lump and small. The proposal is in connection with the installation of new plant for the Dawsholm works, Glasgow. The Scottish coals available are of the type which in lump form give high throughputs in vertical retorts It is therefore proposed to carbonise the coal of over 1 in. particle size in continuous retorts and to blend the remaining fine coal for charging into Woodall-Duckham chamber ovens. Suitable control of blending will then ensure reduction of period of carbonisation, and the production of combustible coke. Preliminary work on blending for such ovens is being conducted by the Research Section of the Woodall-Duckham Company at Ramsgate with the co-operation of the Engineer, Mr. Ruthven.[37] This type of chamber oven seems particularly suitable for such work, although a narrow coke oven such as was used in early experiments by the Woodall-Duckham Company is also suitable the only difficulty being that of possible crushing of uncarbonised material during discharge.

A further advantage of increased rate of throughput is the increased thermal efficiency of the process, as the heat dissipated by radiation, etc., is a function of time and not of throughput.

Constituents of the Blend

Coke breeze is always an available constituent and it is possible that all the breeze now produced could be utilised for this purpose if blending were resorted to for only a portion of the coal carbonised.

If the full value of blending is to be realised, however, it is necessary to visualise the utilisation of as much non-caking coal as possible. In some districts both types are readily available, but in others the added cost of freight or pre-treatment may outweigh the advantages of blending.

COMBUSTIBILITY OF COKE FROM BLENDS

The value of a coal substitute must be regarded to a large extent in the light of its combustibility. Such factors as amount of ash, absence of clinker and soot, and cleanliness in handling, while of domestic importance, must be secondary to the important consideration of a bright cheerful fire. It is now generally recognised that semi-coke is a very promising substitute for coal, and in the following experiments the standard of comparison chosen has been semi-coke made by carbonisation of coal in the low-temperature retorts at H.M. Fuel Research Station.[38] The test employed was the simple and arbitrary one of igniting in a cold grate of well type 8 lb. of the fuel and observing the horizontal component of radiation until the fire had burned down. The test is described here strictly as a means of comparing cokes, and the results have no absolute significance The points of comparison are the amounts of gas necessary to start combustion, the time taken to reach the point of maximum rate of radiation and the rate of radiation at that point.

The first point to be considered was whether residual volatile matter played a part of any importance in determining combustibility. Using low-temperature coke made in the Fuel Research Station vertical retorts as a basis of comparison, low-temperature coke prepared in a smaller retort but from the same coal was carbonised at an external temperature of 600°C. and then heated to 900°C. to remove most of the residual volatile matter. The results as shown in the appendix and in Fig. 4 are striking. The coke prepared at 600°C. contained 8·5 per cent. of volatile matter and behaved similarly to the standard of comparison. The heated coke, in which the volatile matter had been reduced to 2·7 per cent. burned up more slowly and attained its maximum rate of radiation at a much later period.

Residual volatile matter, per cent. ..	8·5	2·7
Gas for ignition, B.Th.U.	1120	1120
Time to reach maximum rate of radiation, mins.	80	105

It may be assumed from this experiment that if domestic smokeless fuel is to be made in gas retorts by blending it is desirable to leave in it some 5 to 8 per cent. of residual volatile matter. Such an

arrangement is not difficult as, owing to the control of the plastic zone the differences in volatile matter throughout the charge are not nearly so great after the lapse of about half the carbonising period as when using coking or gas coals alone.[23]

Experiments on these lines were suggested to the Director of Fuel Research by J. Roberts but no experiments other than those described herein have been carried out.

FIG 4 COMBUSTIBILITY CURVES – COKE SIZE 1"–1¼"

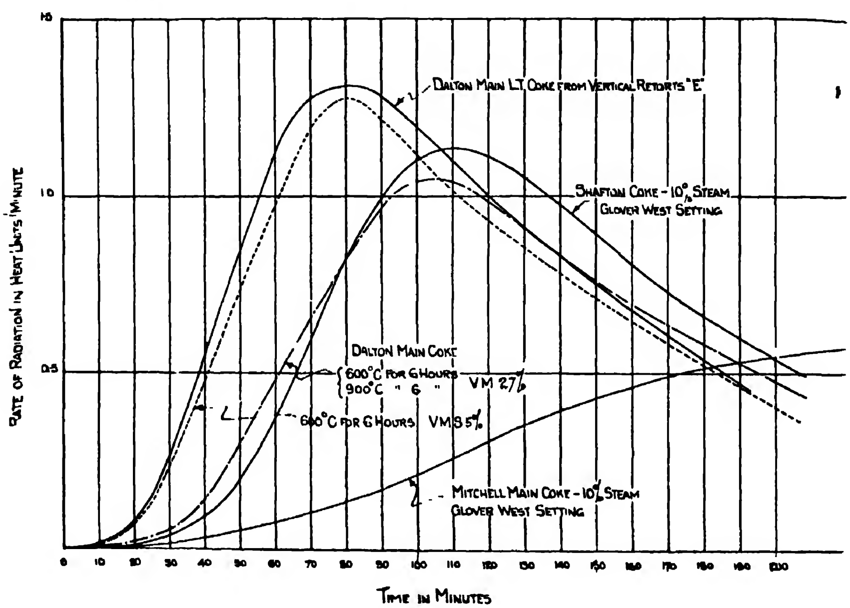


Fig. 4.

Under the conditions of this simple combustibility test the type of coke made in gas retorts compares unfavourably with low-temperature cokes. Coke from Glover-West retorts is difficult to ignite, and gives a flat curve (Fig. 4), while that from a horizontal retort could not be made to burn at all although the centre of the fire was raised to a dull red heat by the gas lighter. Comparison under these conditions is not, of course, intended to discount the evidence of other experimenters who have shown that gasworks coke can be made to burn in other grates and under other conditions.

In Fig. 4 is also shown the curve for coke made in a Glover-West retort from a selected lump coal not normally used for gas-making purposes. This coal possessed in itself the correct amount of binder for the control of the fusion zone, and might be regarded as a blend in which the individual particles were in closer contact. The curve

indicates as good a fuel as the low-temperature coke with a 2·7 per cent. of volatile matter, and is a very considerable improvement on the normal vertical retort coke. From a gas-making point of view this coal gave quite good results, and it is conceivable that it might well repay a fortunately situated gas company to consider the carbonisation of medium caking coal of this type in vertical retorts. The process would probably necessitate screening and the blending of the finer coal for charging to horizontal retorts or ovens.

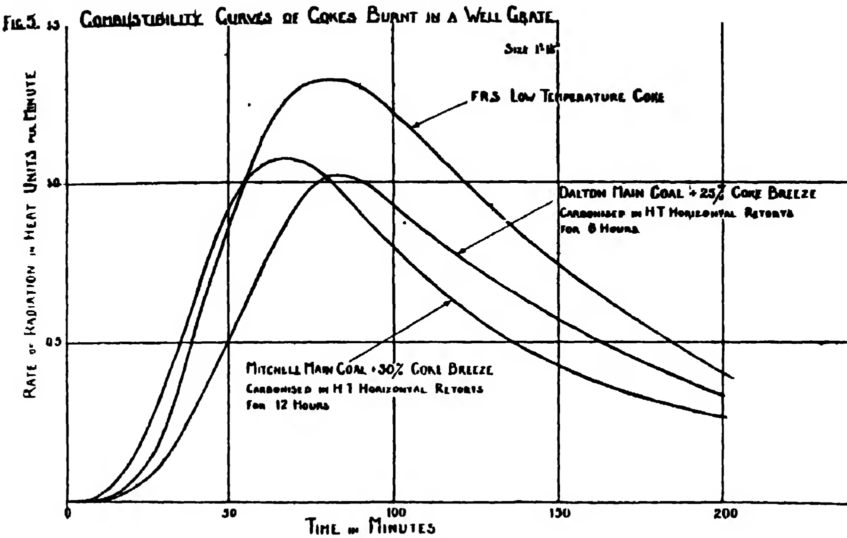


Fig. 5

Similarly, artificially prepared blends would give the same results if sizing by briquetting were resorted to. The more promising procedure is, however, to carbonise stronger blends in horizontal retorts or ovens. Fig. 5 shows curves obtained from two coal coke blends prepared at the Fuel Research Station. All these cokes give satisfactory results but the best is that made from gas coal and coke. The high combustibility of this coke is of special interest in that the charge was given a full period of carbonisation. Although this point has not yet been proved, it is possible, as already stated, that finely divided coke gives a final structure which is more readily combustible than that given by blended coals. In such a coke also the leaving of residual volatile matter does not seem so necessary.

CONCLUSION

From this consideration of the subject of blending from the point of view of smokeless fuel production only it may be concluded that :—

(1) The blending of coals must be done by careful selection to ensure the right distribution and behaviour of the "binder."

(2) Cokes considerably more dense than low-temperature fuels can be made by high-temperature carbonisation of blends of gas or coking coals with weakly-caking coals or cokes.

(3) The strongest cokes are obtainable by fine grinding of both constituents but that the diluting constituent may, if a suitable coal, be of larger particle size. When the diluent is coke it must be finely divided.

(4) The period of carbonisation of blends of coals should be such that the volatile matter remaining in the coke is 6–8 per cent. Where coke is the diluent this does not appear to be so important.

(5) Finally, it is concluded that of the 10 million tons of coke produced annually for sale a high proportion could, by the methods suggested, be made suitable for domestic consumption without decreasing the gaseous thermal output of modern plant and that the production of coke breeze of low value could be prevented. Such a procedure would go some distance towards replacing the 40 million tons of raw coal consumed annually in domestic appliances.

APPENDIX

COMBUSTIBILITY CURVES

The curves shown in Figs. 4 and 5 in the paper were obtained by the combustion in a well grate under identical conditions of equal quantities of the cokes. The data collected for comparison were, gas required for ignition, rate of radiation in a horizontal direction and weight of unconsumed fuel. Each fire of 8 lb. was lit by means of a gas burner and allowed to burn out without disturbance. The coke was crushed and screened to a uniform size (1½ to 1 in.) and air-dried.

It is emphasised that this test is regarded as a comparative one only, and that in more suitable grates normal gas cokes can be made to burn with considerable success.

The results discussed in the paper are given in the following table, the various samples examined being :—

(1) Low-temperature coke produced in the vertical retorts at H.M. Fuel Research Station described in F.R.B. Technical Paper No. 17. The coal used was Dalton Main and the carbonising temperature 625°C.

(2) Low-temperature coke produced in a similar but smaller retort at the Fuel Research Station.

(3) Coke No. 2 prepared at a carbonising temperature of 625°C. and subsequently heated to 900°C. to remove volatile matter.

(4) High-temperature coke produced from Mitchell Main coal under the conditions of gas manufacture in a Glover-West retort employing 10 per cent. of steam.

(5) High-temperature coke as in (4) but employing, in lump form only, a coal of caking power less than average and not generally utilised for the purpose of gas manufacture.

(6) High-temperature coke made by the carbonisation in a horizontal gas retort of a blend of 75 parts of medium caking coal with 25 parts of fine coke.

(7) As for (6) but with 70 parts of a gas coal with 30 parts of fine coke.

Type of coke.	Volatile matter per cent.	Gas for ignition B.Th.U.	Time to maximum rate of radiation. mins.	Maximum rate of radiation per min.	Amount consumed per cent.
*1	6·5	1120	80	1·32	75·0
2	8·5	1120	80	1·28	71·5
3.	2·7	1120	105	1·04	66·8
4	1·0	2800	220	0·58	46·0
5	1·0	2400	110	1·07	65·0
†6	1·0	1120	83	1·02	59·0
†7	2·5	1400	68	1·07	60·0

* Used as standard of comparison.

† A coal blend carbonised in the horizontal retort gave a coke which could not be ignited under these conditions.

NOTE

The author is indebted to Mr H Bardgett, B.Sc., for assistance in the experimental work on carbonisation of blends, and to Mr C W Ockelford for making the photomicrographs in figure 3

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ZUSAMMENFASSUNG

Der Hauptzweck des Mischens, so wie es in der Vergasungsindustrie betrieben wird, besteht in der rationelleren Nutzbarmachung der hochflüchtigen Kohlen, die bisher als Kokskohlen angesehen wurden. Wenn solche Kohlen vor der Vergasung mit einem "verdünnenden" Zusatz, der imstand ist, den vorhandenen "Binder" zu verteilen, gemischt werden, so ergibt sich ein viel gleichmässigerer Koks und eine beschleunigte Vergasung.

Feines Mahlen der Bestandteile und gründliches Mischen sind zur Erzeugung von starkem Koks unumgänglich, doch wo es sich beim "verdünnenden" Zusatz um nichtbackende Kohle handelt, die den "Binder" zu absorbieren und dadurch ein gleichmässiges Schmelzen hervorzurufen imstand ist, braucht diese nicht so fein zerkleinert zu werden. Nichtabsorbierende Zusatzmittel müssen sehr fein zerkleinert werden, und je feiner sie gemahlen sind, desto mehr innert gewisser Grenzen zugesetzt werden sollte. Unter diesem Gesichtswinkel sind Halbkokse mit hohem Gehalt an flüchtigen Bestandteilen bessere "Verdünnungsmittel" als Kokse, die einen geringeren Gehalt an flüchtigen Bestandteilen aufweisen. Im allgemeinen wird die grösste Gleichmässigkeit in der Struktur mit Gemischen aus Kohle und Koks erreicht, doch ist die Dichte des Erzeugnisses bedeutend geringer als die von Kohlengemischen.

Den durch rasches Erhitzen von Mischungen erhaltenen Koksen ist hohe Reaktionsfähigkeit oder Brennbarkeit eigen. Dies ist, wie sich aus der Untersuchung der endgültigen Zellenstruktur ergibt, nicht nur der erhöhten Gleichmässigkeit und den feineren Zellwänden, sondern auch der geeigneteren Oberfläche zuzuschreiben, die ihrerseits auf das, dank der besseren Kontrolle der Schmelzzone und der Wahrung der Porösität in der Beschickung ermöglichte ungehinderte Entweichen der flüchtigen Bestandteile zurückzuführen ist.

Diese erhöhte Reaktionsfähigkeit tritt bei Gemischen aus Koks und Kohle mehr zutage als bei blossen Kohlengemischen, und es scheint daher nicht nötig, flüchtige Rückstände im Koks zurückzulassen, um ein leichtes Entfachen desselben im Hausgebrauch sicherzustellen.

Der Jahresverbrauch an Rohkohle für Hauszwecke beläuft sich für Grossbritannien auf gegen 40 Millionen englische Tonnen. Das Verlorengehen der in dieser Menge enthaltenen Nebenprodukte, sowie die Tatsache, dass dies wahrscheinlich die Hauptursache der Rauchplage ist, geben zu besonderem Interesse an der Erzeugung eines rauchlosen festen Brennstoffes Anlass. Der durch Schwelung erzeugte Halbkoks hat sich bereits als sehr guter Ersatz fur Rohkohle erwiesen, doch ist der wirtschaftliche Erfolg der verschiedenen Verfahren noch nicht genügend sichergestellt, als dass die Kohle schon in bedeutendem Ausmass verdrängt worden wäre. Die Erzeugung von "brennbarem" Koks mittels Mischung von zur Gaserzeugung benutzten Kohlen anstelle des weniger geeigneten Kokses der Gaswerke zeigt eine neue Art, dieses Problem anzupacken. Die ermöglichte raschere Beheizung erlaubt nicht nur das Aufrechterhalten der Erzeugung der erforderlichen Gasmenge je Anlageeinheit, sie liefert auch einen nützlicheren Brennstoff von höherem Handelswert. Ein guter Teil der etwa 10 Millionen englische Tonnen betragenden Erzeugung an Gaswerkskoks hat bereits einen guten ständigen Absatz als Brennstoff in geschlossenen Öfen und umgebauten Rostanlagen gefunden, sodass selbst wenn der ganze Rest "brennbarer" Koks wäre, nur ein kleiner Teil des Hausbedarfes gedeckt werden könnte. Eine erhöhte Produktion an Haushaltsbrennstoffen, sei es durch Schwelung oder in Koksöfen, wäre jedoch nicht durchfuhrbar infolge der Überproduktion an Gas.

GAS MANUFACTURE

THE JOINT FUEL COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS, THE SOCIETY OF CHEMICAL INDUSTRY, THE COKE-OVEN MANAGERS' ASSOCIATION AND THE INSTITUTE OF FUEL

PROF. J. W. COBB, C.B.E.

Paper No. H8

CONTENTS

The present position and attained success of the gas industry depend upon the fact that as a large public service supplying heat, light, and power to the community over wide areas and in many countries, it has replaced the direct use of bituminous coal, with emission of smoke and waste of by-products, by the scientific production and utilisation of smokeless, gaseous, liquid and solid fuels, and accompanying by-products. The future of the industry depends upon how far the processes it applies to coal can be made so efficient and commercially economical, and its products rendered so desirable for use in every way, that the temptation to the direct use of raw coal will disappear. In this paper the position both as to present and future can only be summarised briefly, with no attempt at adequate discussion of any particular point.

In the carbonisation process on which the gas industry is based, the first and most fundamental consideration is that of thermal efficiency, which provides an answer to the question—how many heat units are available in the products (when the heat necessary to carry out the process has been deducted), for every hundred heat units present in the original coal? It may be worth noting for a start that the process itself is a complex of exothermic and

endothermic reactions, which nearly cancel one another in the thermal sense, but the final result is that the potential heat in the whole of the gas, coke, and tar together is usually some two or three per cent. less than that of the original coal. A very accurate estimation is difficult because the retorts used are not gas-tight; but even with a gas-tight retort, the carbon balance nearly always shows a deficiency of 1 per cent. or more, involving a corresponding error in the calculation of heat units.

When we come to look at the process as carried out in gasworks practice, and allow for the heat used and lost in the manufacture, mainly by the consumption of coke in heating retorts, the figures obtainable for thermal efficiency alter as improvements in the design and working of plant are effected, and are of vital importance. It appeared, from a review which was attempted in 1919, that a reasonable figure for normal practice might be taken as 70 per cent., but since that time the subject has received much attention from chemists, engineers and designers and constructors of plant, so that the thermal efficiency of a well-equipped setting of either horizontal or vertical retorts carefully worked with a scientific control of flue gas composition and temperatures, can be taken as approximating to 80 per cent. If waste-heat boilers are used, an additional 5 per cent. is readily obtainable, bringing the efficiency up to 85 per cent. A note of warning may be sounded here, however, that too good a performance of the waste-heat boiler, with its effect on the figure for total thermal efficiency, must not be regarded with complacency, since that may be an indication that gas is escaping from the retorts, and is being utilised as a fuel in the boiler, which is too base a use for such a valuable product.

Apart from retorting, large volumes of gas are made by the water-gas process, either from coke alone, as in the blue water gas plant, or coke plus oil in the carburetted water-gas plant, and the thermal efficiency of those processes may well be indicated here. The thermal efficiency of the blue water-gas process, considered apart from any modification or accessories, appears to be of the order of 46 per cent., taking into account the steam required for the operation of the plant. This figure can be raised, and is now being raised, in most new installations, by the addition of a waste-heat boiler, to some 56 per cent., because of the considerable source of loss in the sensible and potential heat of the blow gases, which can be readily utilised in the boiler. The carburetted

water-gas process is more thermally efficient, because the cracking in the oil is in itself a process with a high thermal efficiency estimated at some 90 per cent. The net result is that in a modern plant carburetting the water-gas up to some 500 B.Th.U. per cubic foot, and with attached waste-heat boilers, a figure of 70 per cent. is obtainable.

In comparing the thermal efficiency of different processes or indeed of the same process worked under different conditions, a careful interpretation is necessary. The figure for thermal efficiency is obtained on the basis of the heat units in the product. It does not take into account that the heat unit when obtained in gas is worth far more than when obtained in coke, so that, in judging any process, the same figure for thermal efficiency represents a better performance when the process is one giving a higher gas yield (in therms). This has to be taken into account, for example, in comparing the efficiencies obtainable with different degrees of steaming in vertical retorts. It has also to be taken into account in comparing the process of carbonisation with that of water-gas production, in which practically all the yield is gas. On the other hand, in considering water-gas, it has to be remembered that the raw material is not coal but coke, on which some thermal and monetary expenditure has already been incurred. For this reason, it is sometimes advantageous to make comparisons by means of the so-called efficiency of gas production rather than efficiency of carbonisation, taking as the thermal efficiency of gas production the heat present in the gas, divided by the heat present in the gas, plus the total heat cost of the process. Such a calculation really regards carbonisation as a one-product process, in which the one-product is made to carry the thermal cost of the whole process.

In practice, there is another limitation of general application to the value of comparison by thermal efficiency alone. It is vital when the possible expansion of the industry is in question, particularly into the industrial field. It is the consideration which makes the financial balance sheet the final arbiter, and arises from the fact that the thermal cost is by no means the only cost which gas has to bear in its production. The following table for works of different sizes illustrates this point. It is there made plain that bounds are set to the replacing of coal by gas by the monetary cost of carbonisation in gas supply for which plant has to be supplied and worked, not only for carbonising coal or gasifying

coke, but for condensing, washing, purifying, storing, and distributing.

TABLE I.

	Gas Light and Coke Company.	Tottenham Gas Company.	Barnet Gas and Water Company.
Therms in gas made p.a. ...	182,854,595	14,834,970	1,350,097
	d.	d.	d.
Coal and oil	4·92	5·24	6·78
Receipts from residual products—			
Coke	2·42	2·01	3·30
Tar	0·73	0·85	0·88
Ammonia	0·30	0·20	0·18
Total from residuals	3·45	3·06	4·36
Coal, etc., less residuals	1·47	2·18	2·42
Net cost in holders (including purification, salaries, maintenance, wages)	4·40	5·78	5·23
Rates and taxes	0·73	0·45	0·67
Distribution (including maintenance of pipes and meters) ...	1·60	2·18	1·85
Capital charges	1·96	1·70	not given
Net cost of gas	7·20	9·21	8·03

The thermal efficiency obtained in the best works by the gas industry and with the latest plant, carefully supervised, is high, although, as in the parallel case of steam raising, there is much to be done and large economies to be secured by bringing the worst up to the average and the average up to the best. Thermal efficiency is, however, not the whole story. It is, I believe, fully realised by the gas industry that the replacement of coal by its products will gradually increase in proportion to the extent that its net costs can be kept down in any way by increase in thermal efficiency (for which in its strictest sense the room is limited) by increasing output, by diminishing capital and other expenditure per unit of operating plant, by utilising all possible sources of fuel supply, whether coal, oil or unused gas, and by increasing as much as possible the value of all its products and by-products. To these problems the gas industry is addressing itself in various ways. Economies and developments may be briefly indicated. Some commercial and technical reorganisation is possible from the amalgamation of undertakings, and some from the fuller utilisation of coke-oven gas, for which there is a *prima-facie* case, since between 3,000 and 4,000 cu. ft. of gas per ton of coal carbonised in coke-ovens would, on the average, be available after providing for the heating of the ovens. The difficulties to be faced in using coke-oven gas are such as those of intermittent supply due to

break-down at the colliery, complete cessation of the supply during coal strikes, variation in quality, the necessity of having sufficient reserve plant in order to meet any sudden failure of the supply of coke-oven gas, maintenance of long length of main, consideration of the position at the end of any contract made when supply would be discontinued and any mains would be of no use, and cost of pumping gas over long distances. These things all require careful consideration.

Other developments may arise when the process of carbonisation has been far more thoroughly and systematically studied than has been the case in the past. Much work is being done in this direction. It is necessary to evaluate separately the factors influencing the results of carbonisation, and that is by no means a simple process. When, however, the choice of coals, their cleaning, size, crushing, blending, and treatment at different rates, temperatures, etc., of carbonisation have all received proper attention, no one can foretell the technical and commercial results that will become practicable. The existing carbonisation processes provide a centre of sound established practice, but will probably have to be varied in detail or even in their main features to meet different requirements. The production of smokeless solid fuel more suitable for domestic use than ordinary gasworks or coke-oven product is an example The most obvious plan for that purpose seems to be carbonisation at a lower temperature, but that would be a reversion for the gas industry, which has developed in the direction of increasing the yield of gas, that is of the product which gives the greatest enhancement of value, both in the thermal and monetary sense. If the gas yield dropped to one half, the whole outlook of the gas industry would be altered. Moreover, making coke at a low temperature has been shown to be only one way, and not at all necessarily the best, of producing solid fuel of high chemical reactivity which will burn cheerfully. Altering the conditions of operation in carbonisation, apart from temperature, influences the cellular structure of the coke and alters its properties in various ways, and interesting results have been obtained in making coke more reactive by the addition of inorganic constituents, such as sodium carbonate, oxide of iron and lime. Rapidity and cheapness in carbonisation are plainly desirable, and for this purpose it is probably not so much low temperature in the charge carbonised that will help, as the construction of an apparatus and method of working, which will allow of a high

temperature head and effective penetration of heat to the charge. For this reason every effort is justified in the direction of improving the quality of refractory materials, both as allowing the use of high temperature heads and of prolonging the period over which structures can remain comparatively gas-tight and efficient in operation. There is some tendency to secure simplicity by carbonisation in bulk, and large chamber retorts are receiving extensive trial in that connection. Exactly the opposite tendency, but still sound in principle, is seen in processes where the greatest rapidity of output is sought by carbonising the charge in dust form, each particle being subjected to the effect of an ascending current of hot gas. As at present worked, however, this process does not yield gas of a sufficiently high grade for public supply. Another method in which simplification is being sought is in the direct gasification of coal instead of coke in the water-gas plant, with necessary modifications which may be extensive. In this connection it may be pointed out that on some of the highly reactive cokes prepared with the addition of inorganic constituents, the rate of gasification obtainable in a current of steam or CO_2 may be increased in some cases ten or twenty times, without lowering the quality of gas produced below a high standard. The following table is of interest in that connection :—

TABLE II.

GASIFICATION OF SPECIAL COKES IN STEAM AND CO_2.

Coke used	Wt. of coke. Grams.	Gas entering.	Rate of gas entering, litres per hour.	Rate of coke gasification. gms./hr.	CO_2 per cent. in gas leaving (Dry)	CO per cent. in gas leaving.	Temp. fuel bed deg. C.
[illegible]	10	Steam	2·5	1·15	5·2	—	1,000
[illegible] per cent Fe_2O_3 ...	10	,,	21·9	10·5	5·0	- -	1,000
[illegible] per cent CaO ...	10	,,	11·2	5·2	5·4	-	1,000
[illegible] per cent Na_2CO_3 .	2·5	,,	19·0	—	5·8	—	1,000
	10	,,	21·0	—	0·4	—	1,000
[illegible]	10	,,	10	0·9	18·0		800
[illegible] per cent Na_2CO_3 ...	10	,,	10	5·8	1·7	—	800
[illegible]	10	CO²	6	—	—	47·8	1,000
[illegible] per cent Fe_2O_3 ...	10	,,	6	— —	—	93·0	1,000
[illegible]	10	,,	6	- —	—	95·0	1,000
Na_2CO_3	10	,,	6	- —	—	97·0	1,000
[illegible]	10	CO²	6	— —	—	14·0	900
[illegible] per cent Fe_2O_3 ...	10	,,	6	—	—	70·0	900
[illegible]	10	,,	6	—	—	63·0	900
Na_2CO_3	10	,,	6	—	—	82·0	900

No claim can be made that the use of such cokes has reached the stage of successful commercial application, but the possibilities are fascinating, and it introduces the principle of controlling the nature of the fuel gasified. There are specially possible applications which may be mentioned, such as that of making a fuel which can be gasified with great rapidity in portable generators for motor transport.

There remains for mention the radical simplification which could be effected in gas making processes if cheap oxygen could be supplied instead of air. It is quite true that at present and for the immediate future the production of a solid smokeless fuel must be regarded as very desirable. The main reason for this, in the opinion of the author, is simply that there is no refuse destructor comparable for general usefulness with the solid fuel fire, and the problem of sanitation is greatly simplified by the existence of one solid fuel fire in each house, serving not only as a heater but as a destructor. Surely, however, this difficulty will be overcome and we shall be able to take full advantage of the higher thermal efficiency, cleanliness, convenience and labour-saving qualities of gas as a fuel. A process of complete and continuous gasification is surely the ideal. The price of oxygen has not yet been brought low enough, but when that has been attained it seems likely that gasification could be effected not only with a high thermal efficiency approximating to 90 per cent., but in a simple continuously working apparatus of the gas-producer type.

Other developments in the gas industry are inevitable in the processes of condensing, washing, and purification. The effluent problem is serious and must be solved. Proper thought and design, even in existing plants will lessen the quantity of that effluent, while bringing down the tar as quickly as possible, separating it as soon as possible from the liquor, and minimising the contact with oxygen, particularly while the tar and liquor are hot, will lessen the production of harmful ingredients. Chemical processes for the extraction of phenols from liquor are being studied.

Tar is a large subject in itself, but so choosing and treating coal-tar as to give it the properties of an ideal road-binder is an aim of immediate importance to which reference should be made.

The ammonia question has become serious because of the lowering of prices resulting from the development of the synthetic

process. It is unfortunate that not one of the processes making the sulphur in the coal the source of the sulphur in ammonium sulphate production has so far met with commercial success. Under the conditions of to-day liquid purification may have better prospects than appeared likely twenty years ago. The removal of H_2S by oxide of iron, although efficient, is much too cumbersome and expensive in plant and labour, while hot oxide purification does not seem to have been worked out to a satisfactory conclusion.

Another kind of process in which the gas industry has an interest is that for the extraction of benzole and motor spirit generally, and in this connection the potentialities of active carbon and of silica gel may become important at any time. The monetary value of motor spirit per therm is high compared with that of coal, but it is only about the same as that of gas, so that, for example, in gas at 10d. per therm, benzole is worth 15.7d. per gallon, roughly the same price as in motor spirit. This lessens the inducement for extraction of benzole or for production of motor spirit from gas. The inducement to recover motor spirit from gas may be increased if it is found practicable to simplify the purification, and so increase the yield, and lessen the consumption of such purifying agents as sulphuric acid. Work is being done in that direction, and it seems likely that by the controlled use of inhibitors, the tendency of crude or partially refined motor spirit to gum formation may be materially lessened or eliminated.

In the foregoing, no consideration has been attempted of processes which are in one sense rather remote from carbonisation and gasification, but must have an interest for all concerned with the scientific utilisation of coal, particularly for the production of motor spirit. I refer to the catalytic treatment of water-gas and hydrogen under pressure, to the making of liquid products known commercially as synthol and methanol, to the hydrogenation of coal under pressure, and to the synthetic production of ammonia. All these demand the preliminary preparation of water-gas or hydrogen, or both, which come within the range of interest of the gas industry. Their consideration may be specially useful to the gas industry, since during the summer season, when the demand for gas and heating agents generally is lessened, part of the plant, particularly the water-gas plant, is thrown out of action and becomes available for other uses if they can be found. The development of these processes is being watched with interest by

the gas industry with the realisation that more active participation may become advisable at any time.

In conclusion, may I say that a fuller review of the present activity of the gas industry has been made by Mr. J. A. Butterfield, and published in the *Journal of the Society of Chemical Industry* (October 1927). Also may I explain that I have purposely omitted names throughout in dealing with the numerous processes and results mentioned above, because otherwise the text would have been overladen therewith.

ZUSAMMENFASSUNG

Die gegenwärtige Lage der Gasindustrie und der von ihr erreichte Erfolg beruhen auf der Tatsache, dass sie als grosses öffentliches, Licht, Kraft und Wärme an die Gemeinschaft lieferndes Unternehmen den unmittelbaren Verbrauch der Steinkohle durch die wissenschaftliche Herstellung und Verwendung gasförmiger, flüssiger und fester rauchloser Brennstoffe und miterzeugter Nebenprodukte ersetzt hat. Ihre Zukunft hängt davon ab, inwieweit es ihr gelingen wird, die auf die Kohle angewandten Verfahren so rationell und rentabel zu gestalten, dass die Versuchung, Rohkohle unmittelbar zu verfeuern, verschwinden wird. Im vorliegenden Bericht kann die gegenwärtige und zukünftige Lage nur kurz zusammengefasst werden; es wird nicht versucht, darin irgend einen besonderen Punkt eingehender zu besprechen.

THE PURIFICATION OF COAL GAS

JOINT FUEL COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS, THE SOCIETY OF CHEMICAL INDUSTRY, THE COKE OVEN MANAGERS' ASSOCIATION AND THE INSTITUTE OF FUEL

CHARLES COOPER

Paper No. H9

CONTENTS

Cooling and Condensation

Cooling of crude gas by air is too uncertain a method, particularly where the gas has a steam content above the average, and it is now for all practical purposes obsolete.

The problem is conveniently taken up starting at the dew-point of the crude gas, as the temperature fall to this point, although it may be due only to air-cooling and radiation, is easily attained owing to the high-temperature gradient obtainable, and the relatively small quantities of heat involved in a given temperature drop, when handling unsaturated gases.

The features common to all heat exchange questions (such as the relation of film coefficients to velocity, and the effects of turbulent motion) all occur, but the cooling of mixtures of steam and permanent gases possesses special features. The main ones are that the heat load per degree of temperature varies with the vapour pressure of water, and that the transmission coefficients alter according to a somewhat similar fashion.

In the "Report on Condensing and Scrubbing" published by the American Gas Association in 1925,[1] a study is made of this particular heat-exchange, and a very convenient method for analysis of results and for design of coolers is given. This method uses a mean

[1] Method of Haug and Mason. The U.G.I. Company, Philadelphia, U.S.A.

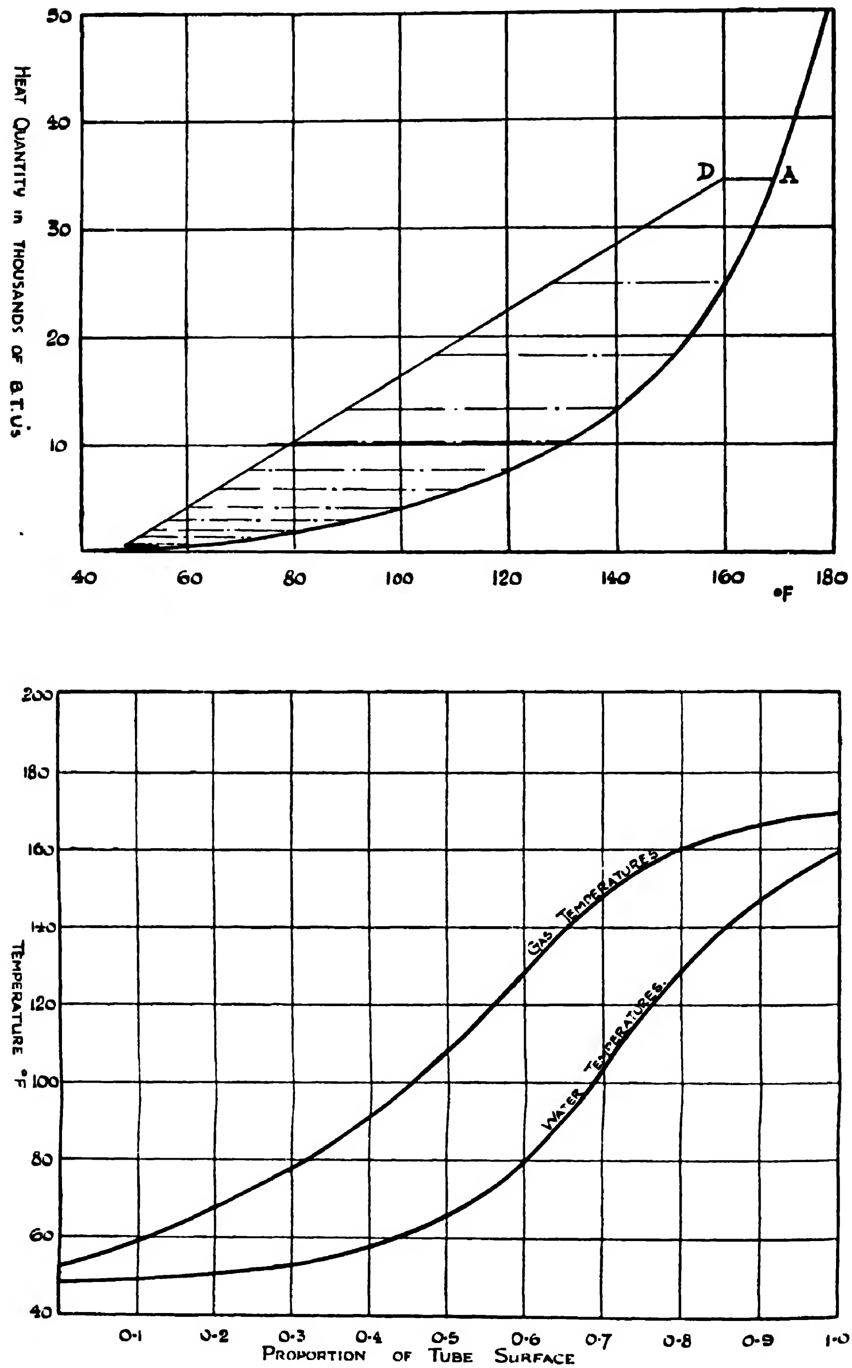

Fig. 1.

[Note at foot of next page.]

temperature difference over the required range which is obtained graphically, and deduces a mean overall heat transfer coefficient for the same range.

Fig. 1 shows details of a test carried out on a horizontally tubed

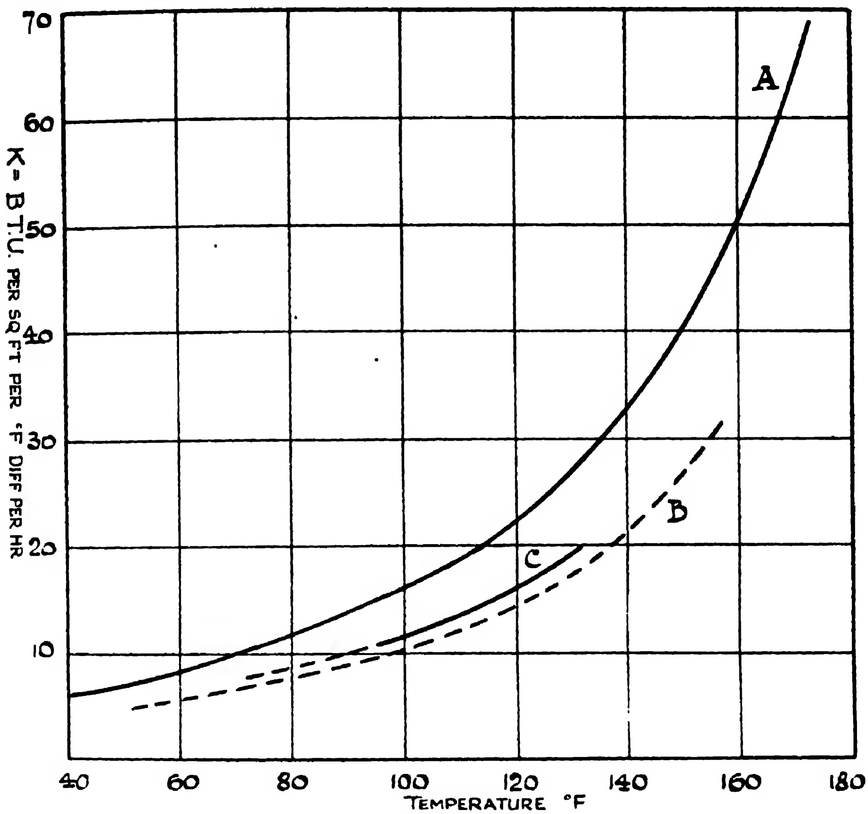

Fig. 2.

Showing Values of K at temperatures 40 to 170°F. for various velocities.

Curve A : Determined from seven separate tests similar to Fig. 1.

,, B : Calculated from the values on Curve A, for velocity 3·6 ft. per second, in ration of 0·76 root of relative velocities.

,, C : Calculated for 4 ft. per second, and showing in full portion exact confirmation from tests on an entirely different installation.

[Note from previous page.]

Drawn from data on a horizontal tubed condenser observing intermediate temperatures.

Gas Inlet Temperature...	A	169°F.
Gas Outlet ,, ...	B	52·8°F.
Water Inlet ,, ...	C	48·7°F.
Water Outlet ,, ...	D	159·4°F.
Cooling Surface	48 sq. ft. per 1,000 cu. ft. per hour. = 2 sq. ft. per 1,000 cu. ft. per day.	

Linear Velocity of gas at 60°F. ... 6 ft. per sec.

NOTE.—The heat quantities given are about 8 per cent. lower than calculated from fully saturated gas and steam mixtures, but give accurate heat balance for the tests quoted.

condenser installation. In this construction the water makes a large number of passes between headers, and allows of the determination of the change of temperature during passage through the condenser.

Consequently it is possible to apply the calculation by the method of Haug and Mason to any temperature range desired, and to find the transfer coefficients for restricted ranges or for particular temperatures, under conditions of practice. Fig. 2 shows the coefficients for various temperatures (determined actually for the range ± 5°F.) for velocities of 6 and 4 ft. per second. These velocities are calculated from the volume of gas measured at 60°F. and 30 in. pressure, and the effective cross-section.

Some of the indications obtained by this means were :

(*a*) Where the water temperature approaches the inlet gas temperature very closely, the transfer coefficient at the highest temperature falls below the expected value, suggesting that the gas is really slightly unsaturated.

(*b*) Comparing the coefficients over the same range as between various types of condensers, it is found that they are nearly double in the case of these horizontally tubed condensers, those of the vertically tubed condensers quoted by Tooby,[2] and approach closely to those for direct cooling given by Rosebaugh.[3] Comparison with the special construction described by Tindale[4] is more difficult but actually appears to show lower coefficients for the latter.

TABLE I.

K. VALUES OVER VARIOUS RANGES

Lower Limit	Upper Limit							
	169°F.	160	150	140	130	120	110	100
120°F.	35·5	34·4	29·9	24·5	20·0	—	—	—
110	33·7	31·9	27·5	22·6	20·3	20·2	—	—
100	32·3	29·7	25·1	21·1	19·2	19·2	19·2	—
90	31·0	28·0	23·5	19·7	18·4	18·4	18·2	17·2
80	28·5	24·9	20·4	17·3	15·6	15·1	14·1	12·0
70	25·6	21·5	17·2	14·4	13·0	12·3	11·4	9·0
60	22·6	18·2	14·5	12·0	10·7	10·1	9·3	8·0
53	20·7	16·3	12·9	10·8	9·7	9·2	8·6	7·7

Table I shows the overall coefficients for various temperature ranges for this type of condenser, obtained by the method outlined

[2] C. F. Tooby. Corporation Gas Works, Coventry, England. See *Gas World*, 81, p. 561.

[3] T. Rosebaugh Pacific Gas & Elec. Co., San Francisco, U.S.A. *Chem. and Met. Eng.*, Mch., 1928., p. 144.

[4] H. Tindale, Sydney, Australia. *Gas Age Record*, Feb. 11, 1928.

above. The figures for the higher ranges agree well together for various determinations, provided that the range does not include the immediate point of entry of the gas.

Consistent results will, of course, only be obtained when the tube surfaces are in normal condition. Deposits of naphthalene occur in some cases in the cooler parts, and in other cases adherent coatings of pitch or dust. To deal with such eventualities it is often the practice to arrange for reversal of the flow of gas, to obtain the benefit of the high temperature, for example, to remove the naphthalene. Dr. Carpenter's[5] method is shown in "Modern Gas Practice" by Alwyne Meade, and a different construction of connections for the same purpose, for a condenser of two passes, is described in E.P. 272,293/1926.[6]

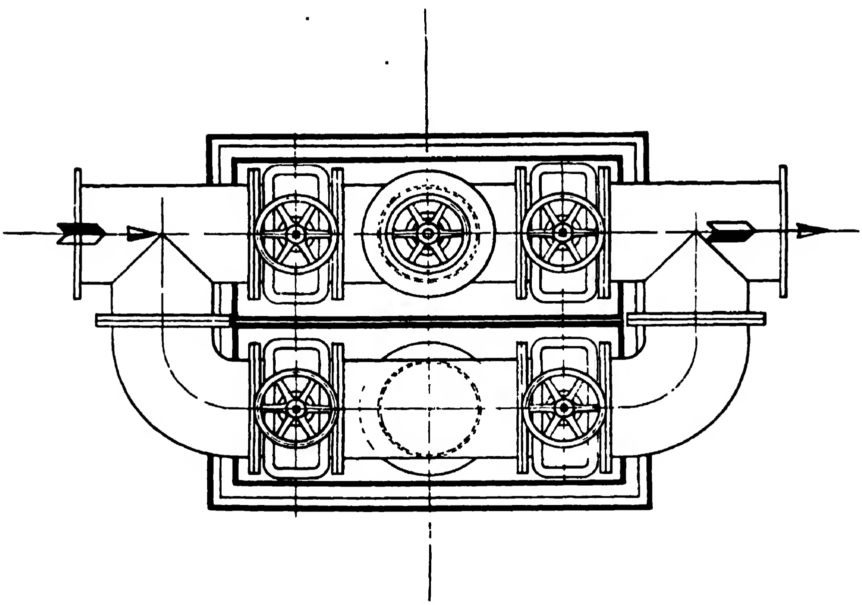

Fig. 3.
Patent Reversible By-Pass for Horizontal Tubed Condenser.
See Reference [6].

DIRECT COOLING

The washer-cooler is most commonly met with in the United States where it has, in many places, displaced the tubular type. It consists of one or more towers with suitable packing, over which the cooled condensate from the gas is caused to circulate. The

[5] C. Carpenter. South Met. Gas Co., London, England. See A. Meade, *Modern Gas Practice*.

[6] D. M. Henshaw. W. C. Holmes & Co. Ltd., Huddersfield, England. See also [11].

heated liquid leaving the tower is thereafter pumped through nests of pipes exposed to the air, and over which the cooling water is flowing. The essential data for this apparatus were published by Steere[7] and an abstract is given in Table II. A detailed examination of these coolers, on the lines of the A.G.A. report above mentioned, has been made by Rosebaugh, reference.[3]

TABLE II.

DATA ON WASHER-COOLER SIZES

Gas Inlet Temp	Gals. of Liquor per minute	Sq. ft. of Cooling Coils	
120°F.	0·22	6·6	Per 1,000 cu. ft. per hour
130	0·26	9·3	
140	0·31	12·8	
150	0·38	17·9	
160	0·49	26·3	

Water consumption: about 0·75 gall. per gall. of liquor circulated.
Area of filling: 5 sq. ft. upwards, per 1,000 cu. ft. of gas passed per day.

The washer-cooler is undoubtedly cheap, but exhibits a few disadvantages. It is usually worked in connection with the so-called intensive ammonia washer, which it resembles; it does not appear to give as good tar extraction as might be expected. It involves a considerable amount of pumping apparatus, and it does not appear from published data to have any special merits as regards water economy.

It is also to be noted that the repeated handling of liquors is regarded to-day as promoting the formation of those constituents which render ammonia plant effluents highly toxic.[8]

On the other hand, the washer-cooler appears to be adaptable to dirty or corrosive waters, which are troublesome in tubular condensers. Salt water in the latter demands cast iron tubes, thus raising the first cost.

An apparatus and principle similar to the washer-cooler is employed by Still[9] in connection with direct ammonia recovery, and is described in his specifications. The work of Feld in connection particularly with the control of the composition of condensates, is

[7] F. W. Steere. Steere Eng. Co., Detroit, Michigan, U.S.A. A.G.A., 1922 Convention.

[8] A. Parker. University of Leeds, England. Paper to Joint Carbonisation Conference, Birmingham, Feb. 21–24, 1928. Also H.M. Inspector of Alkali Works. Reports—1923 onward.

[9] C. Still, Recklinghausen, Germany. E.P. 28,072/1912, 28,245/1913, 147 736/1920.

also important, and can be read in a broad form in the book "Coal Gas Residuals" by F. H. Wagner.[10]

It is a convenient practice to employ the tubular condenser as the feed-water heater for the gas-works boiler, particularly for waste heat boilers in the retort house. Usually the feed-water requirement is below the demands of the condensers, and it has been found[11] that the best method is to divide the duty on the latter, using the boiler feed at the hotter end of the condenser, and perhaps employing an excess of an inferior water for taking the rest of the duty. This method of feed-water heating is not readily applicable to exposed coolers such as the washer cooler.

Another type of direct cooler is employed in the direct system of ammonia recovery in coke oven practice. This usually consists of an empty column down which a powerful jet of cold water is directed. The water requirement is very heavy, and the water is difficult to recondition so as to make it suitable for further use, or for discharge as an effluent. The fact that the hydrocarbons brought down consist largely of naphthalene is chiefly responsible for this design.

Tar Extraction

An excellent survey over the field of tar extraction at the date of its publication is that of Clayton and Skirrow.[12] These authors describe the different types in current use, and discuss methods of estimation of tar fog content.

The most common principle is to employ the difference of density between the tar droplets and the gas to promote separation. The best known apparatus is probably the Pelouze and Audouin, wherein the gas is fairly finely divided into streams, and subjected to a series of quick changes of direction by impinging on steel plate surfaces. Others are the cyclone type which is familiar also for the separation of dust suspensions ; and fans of varying construction, whose beating and centrifugal action also depend on a high relative velocity.

The recent employment of centrifugal exhausters at very high speeds has been found to give improved results in tar extraction, one such machine being said to obviate the necessity of any tar extraction plant other than this. Speaking generally, however, a definite

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[10] F. H. Wagner. The Bartlett-Hayward Company, Baltimore, U.S.A. *Coal Gas Residuals*, The M'Graw-Hill Book Co.

[11] F. C. Briggs, Gas Company, Dudley, England. Presidential address: Midland Assocn. of Gas Engrs. and Managers, Mch. 11, 1926.

[12] R. H. Clayton and F. W. Skirrow. *Gas Journal*, June 4, 1907.

proportion of the tar fog will escape any such apparatus as is included in this class, as the difference of density becomes less effective as the particle size is reduced.

The means employed in the Livesey washer, and its American antitype called the static or multiple washer, appear to be fundamentally different, as such high velocities are not used. In these plants the finely divided gas streams are passed through a few inches of ammoniacal liquor. Undoubtedly surface tension conditions are important in this extractor. It is often favoured for the additional ammonia washing capacity which it simultaneously confers.

Since the advent of vertical retort practice, it is the general experience that good tar extraction is more difficult under such circumstances. This may, in rare cases, be due to condensers becoming inadequate in capacity when turned over from straight gas making in unsteamed retorts, to steamed gas from verticals, but apart from this the tar fog is more persistent in the gas.

One factor which may contribute to the condition stated is that the vertical gases contain a greater proportion of light oils, and condensation of such oils may still be going on at lower temperatures than were required to effect substantially complete condensation, under the conditions of horizontal retort practice.

It was until quite recently considered essential to good tar extraction to pass the gas into the tar extractor at a temperature of 90° to 100°F., and to have secondary condensers to complete the cooling of the gas. This appears to have been connected with the matter of the viscosity of the tar produced under horizontal retort conditions with high heats. Such precaution is not usually taken when dealing with the lighter tars from vertical retorts, and it is probably best to cool the gas as completely as possible before the final tar extraction.

Electrical Precipitation

An interesting and comparatively recent development is the application of the high-tension electric field to the resolution of tar fog.

The Cottrell process[13] is in use in several works in the United States, chiefly very large ones. A constant high potential gradient of the order of 10,000 volts per inch of space is maintained, and the tar drops and vesicles, picking up a negative charge, are thereby attracted to the anode and are collected thereon.

[13] N. W. Sultzer *Gas Age Record*, April 14, 1928.

The principle is simple and the results claimed are very good. Th chief feature requiring careful attention appears to be the maintenance of the insulation in the gas space, and not much trouble appears to arise if the insulators are regularly cleaned.

The cost of an installation on these lines appears to be about three times that of a P. and A. apparatus, and there is an operating cost of, say, 0·1 pence per 1,000 ft. as cost of current, for an installation of 5,000,000 cu. ft. daily capacity (cost of current taken at 1d. per kWh).

The importance of tar extraction appears chiefly in two directions. It has been repeatedly shown that the earlier the tar is removed from the condensing system, the less is the tar-acid content of the ammonia liquor produced. The liquors produced in the later stages of condensation undoubtedly absorb tar acids in greater proportion than those first deposited. On the other hand, a gas cleaned from tar fog is more easy to treat in the later stages of purification, ammonia washing and sulphur removal. Tar reduces the efficiency of most ammonia washers, whether mechanical or static ; and it is easily shown that a very moderate deposit of tar in an oxide purifier can put it out of action, at least temporarily. The loss of tar in such suspensions as are usually found where tar extraction is faulty is seldom important, but the ill-effects can be serious.

Ammonia Washing.

The removal of ammonia from crude gas by washing with water is still the general practice in gas manufacture, as distinct from its removal by direct contact with an acid, which is found most generally in coke oven plants. It is at the first view the simplest method to adopt, as there is already formed a certain amount of aqueous solution in the condensing process.

Another factor, however, which makes water washing a convenience in gasworks is that the rate of production is far from uniform. There is the seasonal variation of demand, and there is also in many works a daily cycle of variations, dependent on the system of retort charging ; on the coke works there is no variation if it can be avoided. Thus the various direct systems of sulphate of ammonia manufacture found in the latter works can be operated on a constant and preferably a maximum rate ; but on the other hand, the indirect ammonia plant can be operated for definite spells at its maximum rate in spite of the varying rate of production, by arranging for the storage of the ammonia liquors made by washing with water.

From a good British gas coal we may expect to obtain about 7 lbs. of ammonia per ton of coal carbonised. The quantity of water in the crude gas will vary between, say, one-tenth and one-fifth of the weight of the coal, depending on the retort house practice. If no more water than this were brought into the system, the ammonia solution which could be made would have a strength of between 3 per cent. and 1·5 per cent.

The condensation process does not, however, give such complete removal, and the quantity of water which has to be employed to absorb the residue depends on :—

The volume of gas to be treated.

The temperature of the washing system.

The efficiency of the washing plant.

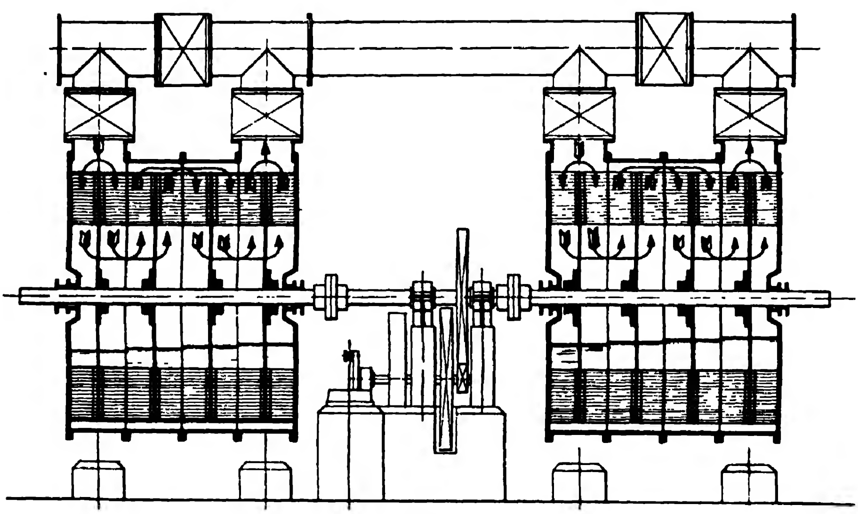

Fig. 4.
Section of Rotary Brush Washer, showing principle of operation.

To a minor degree it also depends on the concentration of ammonia in the gas. This follows from the fact that a certain amount being allowed to remain in the gas, the proportion of removal required will rise or fall as the original content is higher or lower.

The accommodation of a fixed washer capacity to this requirement is naturally made by increasing or decreasing the water flow, though not necessarily in proportion to the original ammonia content.

Liquor Strengths Attainable

If the yield of gas in the above cases is taken at 13,000 cu. ft. per

ton, it will generally result that about 8 gals. of water per 10,000 ft., or say 10 gals. of water per ton of coal will be demanded by the washing plant.

Hence our ammonia liquors will ultimately leave the plant at an average strength of 2·1 per cent to 1·2 per cent.

The above figures are probably representative, but cases arise outside these limits. The usual exceptions are works employing vertical retorts where heavy steaming is practised and a large proportion of steam is passing undecomposed. Such conditions may clearly set up a somewhat high temperature in the washing plant if the condensers are not fully adequate ; and to carry out a high proportion of removal in the washer will require a larger flow of clean water, and the final liquor strength is thus impaired by both these conditions.

It is claimed that the practice of steaming gives a higher yield of ammonia from the coal, but this higher yield does not seem to be in anything like the proportion of dilution set up by the steaming. It follows, therefore, that the liquors from steamed retorts are usually weaker than those from other carbonising systems, in spite of a higher total yield.

The proposals of Cobb and Marson[14] to carry out carbonisation and steaming of coals treated with alkalies may become of interest in this connection, as they find that the coke becomes highly reactive to steam, and the undecomposed proportion of the steam is remarkably low. The study of blending and other means of increasing the reactivity of coke is already producing some results in this direction.

The dilution of the ammonia liquor results in increased steam consumption for the subsequent distillation on the ammonia plant.

The matter of the gross volume of the effluent from the ammonia plant, and the total quantity of toxic substances therein are also important as dictating that attention should be given to keeping down the quantity of steam in the gas leaving the retort.

Ammonia Absorption from Crude Gas

The absorption of ammonia in water in the washers does not quite follow the simple laws usually assumed when treating absorption from a theoretical point of view. The presence of CO_2 and H_2S influences the course of events fundamentally. Speaking broadly, a washer wherein clean water is brought into contact with the stream

[14] C. B. Marson and J. W. Cobb, University of Leeds, England. Gas Fellowship Reports to the Institute of Gas Engineers, 1925-6.

of crude gas in counter-current, will show characteristics indicating that the conditions at the water inlet end approximate to those of the removal of ammonia in the absence of the acid gases, although these are present ; and that these conditions merge almost immediately into those expected in the presence of the acid gases. The partial pressure of a fairly strong gas liquor is about one-ninth of that of an equivalent solution of ammonium hydrate, and this difference is what is reflected in the state of affairs described.

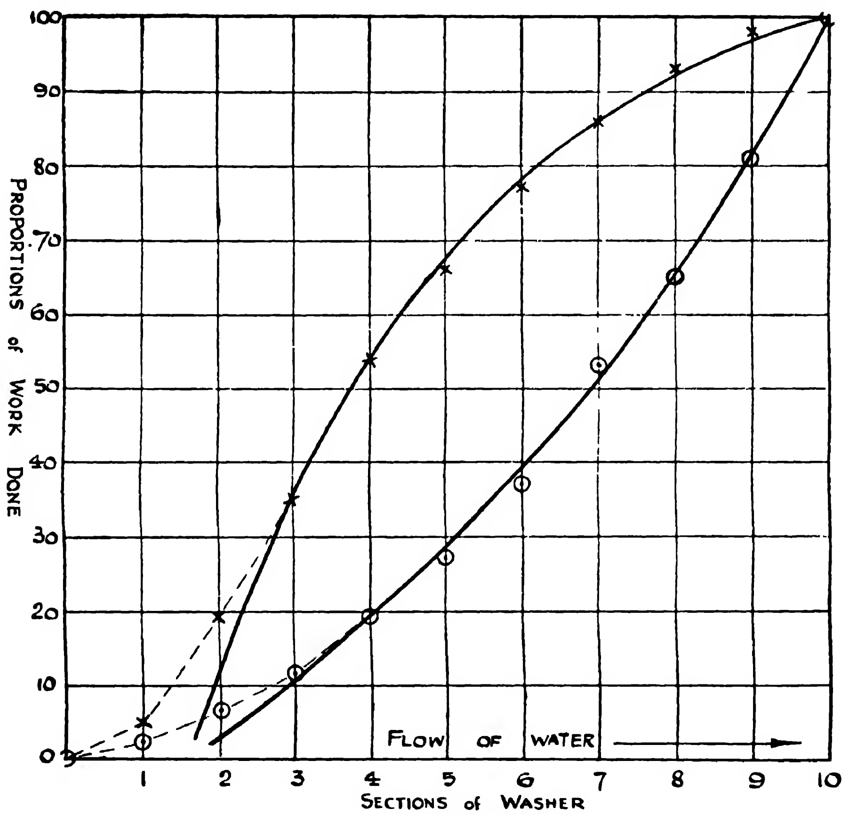

Fig. 5.

The points indicated are actual concentrations of ammonia in the liquors in successive sections of a mechanical washer, represented as proportions of the concentration finally attained. In the higher range a geometrical progression is approximated to, and the lines are drawn through the points representing such progressions.

Fig. 5 shows values taken from actual tests, and is typical of this particular reaction. The ordinates show the building up of ammonia concentration in the different steps of the mechanical washer. In the larger right-hand area, the curve approximates closely to a

geometrical progression (which is shown by the line which represents the sums of calculated geometrical series), but in the left-hand area, where the liquor strengths are low, that is at the water inlet, a departure is found in a direction which shows at first a slower building-up, that is, a higher partial pressure of the dissolved ammonia. It should be added that where the acid gases are entirely absent throughout, the steps work out very accurately on the lines of a geometrical progression.

Systems of Washing

In Europe gasworks practice has consistently followed the lines of the various types of mechanical washer, which are alike in this, that they employ a general counter-current principle, but incorporate a number of single contacts which individually are not of a counter-current mechanism. American works have washers of these types, but there has been a considerable turn-over to a multiple series of tower scrubbers. These are the same apparatus as the washer-coolers previously described, but without the external cooling coils. There have been developments in Europe recently on these lines,[15] but at the time of writing nothing has appeared to show whether they represent any advance in technique.

Any of these systems may be found associated with the Livesey type washer, which we have mentioned in its function as a tar extractor. It is common practice to feed this washer with the strong liquor from the ammonia washer in counter-current with the gas.

The success of the mechanical washer is found in that the accurate distribution of the gas and liquid streams is guaranteed by the controlled movement of the washing surface as well as by the actual construction of the apparatus. Comparing this with a single tower scrubber, the latter depends primarily on its structure only, and the forces of gravity procure the necessary movement.

The mechanical washer has in this the advantage, whereas its disadvantage theoretically lies in that it can have only a finite number of steps. This disadvantage, is as we shall see, only apparent, that is, as compared with the single tower scrubber which, according to current theory, should be free from such a limitation.

The multiple series of towers mentioned above has the same characteristics as the mechanical washer, in that each contact is carried out with disregard of strict counter-current (a rapid

[15] R. Miles, Newton Chambers & Co. Ltd., Sheffield, England. *Gas Journal*, May 2, 1928.

re-circulation of liquid is maintained through each tower, whilst a properly proportioned feed of water is given to that tower in which the gas is treated last; an intermediate receiving tank overflows, in virtue of this feed, into the next stronger). Usually, by means of a centrally placed vertical partition, the gas and liquid are made to descend together in half of the scrubbers, and in the other half the gas ascends; an obvious convenience of construction.

This washing apparatus, therefore, seeks the positiveness of distribution given by the rotary types, along with the cheapness and simplicity of tower fillings as contact surface. In actual fact it is usual to have only four to eight individual contacts, whereas the rotary machines commonly have from eight to twelve, or even more.

Limits of Performance

The importance of these considerations lies in this, that the process of washing gas free from ammonia with water is probably the most exacting demanded of washing apparatus in gasworks to-day. The highest efficiency is demanded because a large proportion of removal (often 98–99%) is required, along with the maximum concentration of the wash liquid. Using the parallel often drawn between gas washing and heat exchange, it is equivalent to the demand that a hot fluid should be cooled within a fraction of a degree of the cooling means, using for the purpose the minimum flow of the latter.

The simplest way of perceiving the point at issue is to consider that in a sectional contact apparatus, such as the rotary washer, the gas is finally treated, not with the pure wash-liquid (in this case clean water), but with the product of reaction in the last contact chamber, at the maximum concentration which it can attain in that chamber. Obviously, therefore, there is an advantage in dividing the available washing surface into as many separate contact chambers as possible, whilst maintaining strict counter-current flow in the series.

A full theoretical examination of this question is not possible in the present circumstances, but an illustration of the point is given in the Third Report of the Research Committee of the National Benzole Association of Great Britain, p. 147. A paper by Masson and McEwan also deals with this and kindred matters.[16]

It was mentioned that the single tower scrubber is usually regarded as independent of any such considerations. According to the writer's view, however, this is hardly the case. The formulae

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[16] J.S.C.I., 1921, 32 T.

usually employed to show the properties of these scrubbers, such as that of Donnan and Masson[17] are strictly parallel to the general formula for heat-exchange apparatus,[18] and are really independent of any relative dimensions such as height : diameter. A velocity coefficient may be incorporated, but this is not quite the same thing.

TOWER SCRUBBERS

It is possible to regard a tower scrubber on the same lines as a sectional scrubber ; that is, as a series of contact vessels between which counter-current exists, but within each contact strict counter current is departed from.

Any section of a perfect tower scrubber should have the property that the ultimate possible transfer in an infinite time of passage is represented by an exact exchange of the extreme concentrations for one of the streams. This property depends on the distribution and the tower filling being perfectly uniform and homogeneous.

A more or less consistent departure from such perfection may be assumed for a practical construction. Thus an actual tower can be imagined as made up of a series of sections of reduced height : diameter ratio, in each of which the falling away from exact conditions is represented as equivalent to the bye-passing out of contact of a certain proportion of the liquid flow. A good filling would achieve such a standard with a small height : diameter ratio, and a less efficient one would demand a larger ratio.

Consequently there is here an indication of the necessity for a larger height : diameter ratio for the poorer grades of filling materials. The tower must have not less than a certain number of sections, each of the required standard, in order to make the best use of the contact area it contains.

This leads to two conclusions which are parallel with the known properties of sectional contact apparatus. For any specified service there is a minimum value of n, the number of separate contacts, and there is also a value of n beyond which the advantage of division practically disappears, and the cost of the apparatus will generally rise as the value of n is increased.

(When increasing the value of n it is assumed that the total surface of contact is held constant. The increase in value of n is obtained, of course, by raising the height : diameter ratio, which makes possible the regarding of the tower as made up of more sections each of the standard property in respect of distribution.)

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[17] J.S.C.I. 1920, 236 T. Also: J. Brown. J.S.C.I., 1925, 410 T.
[18] Van Arsdel. *Chem. and Met. Eng.*, 1920, p. 1115.

Entrainment of wash liquid in the gas is also found to have an effect equivalent to the diminution of the effective number of contact sections. This effect of entrainment, in limiting the capacity of counter-current apparatus for washing and distilling, is frequently attributed to other circumstances, and is, in the author's opinion, present in many cases where it is not suspected.

In connection with the general theory of counter-current washing, it may be noted that the main considerations governing the use of towers in series are dealt with in a paper by Still.[19] It is shown that the capacity of the installation is at the maximum when exact counter-current holds throughout the series. In practice each tower is given a larger flow of liquid, by recirculating, than is actually demanded. Obviously this must be done to overcome the faults of distribution which would show more definitely if the minimum flow, equal to the liquid input, were alone circulated. This paper is worked out as for benzole removal, but applies equally to any series of towers, such as the intensive scrubbers of American gas practice.

WASHERS

The mechanical washers in common use are of two main types. The horizontal rotary machine (Fig. 4) has a mass of contact surfaces mounted on a rotating shaft which causes the washing surface to be continually re-wetted before presentation to the gas. This apparatus is, for a given service, high in first cost, but if well designed and constructed will compensate for this by long life and low upkeep charges.

The various centrifugal washing machines create a series of contacts in separated chambers by projecting quantities of the wash liquid as spray through the gas stream. The sprayed liquid returns to the same tray from which it was drawn, and the appropriate rate of counter-current flow goes on by gravity, independently of this mechanical movement

In the design of such machines two facts of importance have to be kept in mind: the limitation imposed by the necessarily finite number of contacts operates even if the extension of the surface be enormously increased. Therefore, there is an economic limit to the amount of such surface which need be created. Further, there is the disadvantage of entrainment if the sprays be of too fine character. Any carrying over of spray with the gas reduces the efficiency.

[19] C. Still. Gluckauf, 1908–9 Reprinted by Coke and Gas Ovens, Ltd., and by the Coke Oven Mgrs. Assocn. Year-Book, 1920.

which can only be met by an increase in the wash-liquid, which is undesirable.

WASHING BY ACIDS

The retaining of volume of ammonia liquors at the lowest practicable figure being found to be so important in the economy of gasworks, it is not surprising that attempts have been made to eliminate the final washing process in various ways. These have generally taken the form of converting the ammonia not absorbed into the water of condensation, into the sulphate. The general type of such plant is found in its complete form in the semi-direct system of recovery on coke plant, used by Koppers originally.

This recovery method has apparently not been applied hitherto in gasworks using other than oven benches.[20]

A large works in this country will, however, shortly come into operation, where mixed horizontal and vertical retort gases will be treated on the semi-direct system. Another system, however, is in successful operation at various works wherein the cooled condenser liquor is brought into contact with the gas after cooling and tar extraction, thus ensuring that the maximum absorption has taken place into such liquor, and thereafter the gas is washed free of ammonia by bubbling through sulphuric acid (admixed, of course, with water and ammonium sulphate). Early plants on these lines seem to have had but moderate results, but recent surveys on two fairly large installations [21] show that there is no reason why success should not be attained.

Some water is likely to be contributed, particularly in cold weather, from the gas by condensation and absorption. In such weather, it may be noted, the ammonia content of the gas will be below the average.

It was formerly reported that the gas which had been so treated was liable to create difficulties in oxide purifiers, as a result of entrainment of acid. These reports appear to apply to some small and early plants and it does not appear to occur in later ones.

It should be noted that the operators of these plants find it possible and advisable to allow a trace of ammonia to pass the washer, to maintain the maximum activity in the purifiers.

The advantages of working with the acid catch are quite appreciable, but too much must not be expected. The full advantages are,

[20] L. H. Sensicle, Gas Company, Newcastle-upon-Tyne, England. *Gas Journal*, May 9, 1928.

[21] These installations are at the Gasworks at Stockport and Pitwines (Bournemouth).

of course, only possible to works which possess a sulphate of ammonia plant. In view of the general tendency for by-product sulphate to become unremunerative, and of the possibility that centralised treatment of ammonia liquors may shortly be the only means of combating this tendency, the opportunities for the wide adoption of acid treatment may disappear.

Gas Drying

The first proposal to distribute coal gas in a dehydrated state appears to have come from Lucien Brémond of the Versailles Gas works, and his objects and methods can be read in E.P. 997 of 1877.

The only advantage desired was to inhibit the deposition of naphthalene, which it is positively stated is to be procured by dehydration.

Brémond, according to this specification, demands dehydration "to the utmost," and the reason for this would appear from an article published in the "Journal du Gaz et de L'Electricité," which was abstracted in the "Gas World" of 1888.[22]

Brémond here states that naphthalene can be produced in the gas after leaving the purifiers, by interaction between water vapour and other gas constituents in the cold. In consequence of this somewhat unorthodox view he must have complete dehydration, and therefore cites only such agents, whether liquid or solid, for dehydrating as will give complete dehydration.

Later, dehydration of air for furnaces (*e.g.*, blast furnaces), was proposed by various means, including most of the practicable methods. The importance of dehydration of air in the blast furnace is to prevent the formation of water-gas, which reaction, by absorbing heat, reduces the temperature in the furnace measurably, and cuts down output more than in proportion to this heat.

Mention has more than once been made in the technical press to the superior condition of dry meters used on natural gas, which is distributed dry on account of its having been released from pressure in the oil measures ; and it was suggested that means would be found in the future to procure this condition in manufactured gas.

Moisture in distributed gas appears to require at least two conditions in order to appear as a harmful impurity. These two conditions are that at some point it should be condensed to the liquid state, and that there should be some oxygen present at the same time. It is doubtful whether other agents which have been

[22] Vol. 8, p. 1[illegible].

cited are effective in the absence of these conditions. Experiments conducted by the author and others[23] [24] tend to this view.

At a point nearing saturation there is slight attack on iron, in the apparent absence of liquid deposits, but it is probable that there is an adsorbed film of water under these circumstances, which is not perceptible by ordinary means. The rate of corrosion was in one case, employing gas at about 90 per cent. saturation, estimated to be of the order of one hundredth of the rate found with the same gas under conditions of complete saturation : *i.e.*, with a perceptible deposit of water present.

It appears, therefore, that the important requirement is that gas being distributed should be so far dehydrated that it will be free from the possibility of further condensation throughout its journey to the point of consumption. The climatic conditions chiefly will dictate what margin should be allowed. Statistics are not available for more than one or two regions, but so far it appears that a proportion of removal of 50 per cent. to 60 per cent. will cover most demands in this respect.

This aspect of the question has been reviewed by Harris[25] in the first description of actual operation of a plant for water removal from gas.

Previous to this a comprehensive examination of the possibilities of various methods of dehydration of gas was made by Sperr,[26] including four groups : compression, refrigeration, chemical and physical absorption and adsorption.

It is clear that in the absence of some special circumstances, each of these represents the necessity of a cyclic process. This appears most clearly in the case of the refrigeration method ; and the power demand of the compression method could be brought into line with this statement. The absorption and adsorption processes employ a reagent which has to be regenerated (or removed entirely from the system, which would make one of the special circumstances just mentioned).

In the case of the compression and refrigeration processes it is easily seen to be true that the further the process is carried the more

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[23] E. Ott and F. Hinden. Monats-Bulletin Schweizer V. Gas Wasserfach, 1927, Nos. 1–2.

[24] F. C. Smith, Gas Light and Coke Co., London, England. *Gas Journal*, April 11, 1928.

[25] C. Harris, Gas Company, Taunton, England. *Gas Journal*, Nov. 23, 1927.

[26] F. W. Sperr, Jr., Koppers Co., Pittsburgh, U.S.A. A.G.A.—1926 Convention.

expensive it becomes, particularly when compared with the diminishing quantities of water removed. The same is true of the absorption and adsorption, where for example the regeneration is carried out by re-evaporation of the diluted agent. This consideration destroys any distinction between agents such as sulphuric acid, silica gel, etc., which can give substantially complete removal if desired, and the agents such as salt and other solutions, which are applicable up to a certain proportionate removal only, if the desirable and economic limit of dehydration is within the field of the latter.

This condition appears to be existent, and the choice of an agent will probably depend on other characteristics than the ultimate possibilities of the substance. Some other results of this conclusion will appear later.

Compression

Power cost will be the primary consideration in the question of whether to compress, and how far. To create a sufficient margin of dehydration, a pressure, say, of 30 lb. gauge will be required, and immediate cooling of the gas to retain the water at the point of compression. The power consumption can be estimated at 80 H.P. per million feet treated, and the water for cooling at 20,000 gals. per million feet.

Installation cost is to be reckoned high in comparison with other methods, even when distribution is effected at a pressure approaching that of the dehydration apparatus. In fact, in such cases, it would probably be preferred to have a duplicate compressor for standby. If distribution at low pressure is intended it would be possible to recover some of the power cost by causing the re-expansion to do work. This would again imply a higher first cost.

Reference should be made to the report on "Dust and Moisture Control" to the Pacific Coast Gas Association, 34th Annual Meeting.[27]

Compression plant would presumably require continuous supervision, on the lines of exhausting plant, and would have to register accurately therewith, or with the momentary rate of consumption. No particular difficulties seem likely to arise in this respect.

Refrigeration

The refrigeration method starts out with the handicap that the whole mass of the gas has to be cooled, a heat load being thus incurred which cannot be turned to useful account, unless it is

[27] Gas Age Record. Nov. 26, 1927. p. 811.

through heat exchange with the incoming gas. With certain grades of gas, undesirable deposition of bodies other than water is likely to occur; and if cooling below 32°F. were practised, trouble with solidification of ice would arise.

Actual proposals[28] appear to have been made to limit the treatment to washing gas with refrigerated water, which obviates the last possibility. It does not appear to the writer that a sufficient dehydrating effect can be hoped for by such means. The minimum temperature of the water is above its freezing point by a considerable margin; a further margin is necessarily implied between this temperature and the dewpoint of the treated gas; and (in the apparatus actually proposed, which employs atomising sprays to effect the contact) any entrainment effects will give a further step away from the minimum. With all these margins it is estimated that the best result possible is a dewpoint of 40°F. In the article by Bragg it is stated that this should be sufficient, but it is difficult to believe that this statement will be justified. Even in England, where conditions are, relatively, equable and mild, the writer has found gas leaving holders at 35°F. over long periods, and has received reports of frozen service pipes, chiefly on street lighting.

In countries where underground mains have been found frozen, the safe dewpoint must be very low at times.

In this country, at any rate, it would be a doubtful and difficult proposition to put before the medium and small works, as the plant would require a class of supervision which could not readily be accorded, at least without a special and large charge; this would be particularly observed, as against the result achievable, and in comparison with other possible processes.

The necessity of dealing with deposits of naphthalene and other hydrocarbons would doubtless vary at different works, but, except so far as the former was removed, would not add to the attractiveness of the process.

Absorption and Adsorption Processes

It is quite clear in considering the compression and refrigeration proposals, that the main matter is how far to carry the intensity of the treatment, and the cost incurred at the stage chosen.

Exactly parallel considerations apply to most of the possible treatments which come under the above heads. So far, the agents which appear to have been proposed for the actual dehydration of the gas are:—

[28] G. A. Bragg. Gas Age Record. Feb. 4, 1928.

Saturated solutions of salts (*e.g.*, calcium chloride) as in the process described by Harris.[25]

Solid reagents (*e.g.*, lime, calcium chloride).

Sulphuric acid.

Phosphoric acid.

Glycerin.

Silica gel.

Reports are available at the present moment only on the first of these proposals, which has been adopted in about 20 works, all in Great Britain.

The theory can be applied to all these possible processes in the following manner :—

In all cases, except perhaps where sulphuric acid is proposed, the necessity of regeneration has to be considered. Consequently, whatever fraction of the saturation pressure of water is to be the object of the process, the reagent, diluted below the concentration appropriate to give this result, has to be brought back to a state of useful concentration. The maximum effect is, therefore, regulated, amongst other factors, by this : the absorbed water must be expelled from the reagent, which is such that it has always a vapour pressure only a fraction of the saturation pressure of water. Thus it will be seen that the higher proportions of water vapour removal from the gas, if desired, will always demand a more rigorous after-treatment of the absorbent, and the extra removal in the absorber will be progressively more slender, as the regeneration of the absorbent becomes more difficult.

The second important circumstance to note is that there is in every case a heat evolution more or less proportional to the quantity of water absorbed (*i.e.*, brought into the liquid or solid state). The re-acting vessel, therefore, tends to suffer a rise in temperature. Such a rise, by raising the vapour pressure of the absorbent, reduces the power of absorption of the reagent, which power is necessarily proportional to the difference of vapour pressures between the gas and the reagent. The latter can conceivably be such that the effect of such a temperature rise will be negligible (as in the case of strong sulphuric acid, or silica gel in a highly active condition) but the continued repetition of the action in a cyclic process depends, as we have seen, on the possibility of regeneration.

It has been proposed[26] to employ sulphuric acid at a suitable concentration, and after dilution to transfer it to a sulphate of ammonia plant. Whether this process can be used without ill effects on the gas, the writer is not prepared to say, but its adoption

presupposes the existence of the sulphate plant, and a duplicate acid storage; or alternatively a buyer for the acid after its absorption of water and any other impurities it may have acquired. Another important objection is that it is by no means certain that a sulphate plant will take care of the additional water thus introduced into the saturator. The problem then becomes again one of evaporation.

Reverting to the temperature rise, which can be easily and accurately calculated from the moisture absorbed, with careful note that as the temperature rises the absorption progressively decreases; and with one or two minor corrections on the lines of heats of dilution, we may note here that with uncontrolled rise of temperature, an absorbent capable, according to its measured vapour pressure, of reducing the moisture content of the gas to one-tenth of the saturation pressure, will, if applied to gas at 70°F., cause a rise to about 108°F., with the result that only 64 per cent. of the water content of the gas, entering saturated at 70°, will be removed. This result could be equally well achieved by using an absorbent with power to take up exactly 64 per cent., and controlling the temperature so that the final contact of the gas with the fresh reagent was at a temperature no higher than the original.

These conditions are fulfilled by the process quoted as in use in this country, and which has now, on one works, been successfully operated for two years.[25] The results, as regards maintaining a water-free distributing system, have been realised throughout, and the cost, which although the works in question is of only approximately 1 million ft. per day maximum output, is under 0·25d. per 1,000 ft. treated, has been much more than repaid by the cessation of complaints, and the progressive reduction in rate of degradation of dry meters. The life of iron parts in the pipes and services cannot, of course, be said to be known under the new conditions, but there is clearly good reason to hope that, internally, their condition will remain unimpaired. Direct experiment, so far, is confirmatory.

The proportion of removal which has given these results is about 60 per cent. from the saturation pressure, and is obtained by the use of calcium chloride solution as the absorbing agent. In our climate, at any rate, there would not seem to be any necessity for going beyond this proportion.[29] This conclusion is supported by similar results on other installations, including one which operates

[29] A. Marsden, Gas Company, Bristol, England. Pres. Address: Western Jun. Gas Association, April 14, 1928.

at the outlet of the gasholder[30] at the rate of consumption ; and by a study of such data on relative ground and air temperatures as are available. It should be borne in mind that such an absorption process gives a progressively lower dewpoint according to the temperature at which the gas enters, and also according to that of the cooling water available. Thus it works generally in sympathy with all the broader climatic variations, and there is found to be a margin of safety to cover the temporary and accidental variations.

The following comparison of proposed absorbents may be made :—

SULPHURIC ACID: Cheap and effective. Requires special plant. Regeneration not advised, preferably used for other purposes. Possible reactions with gas constituents.

SOLIDS : Calcium chloride. Silica Gel. Difficult to handle in cyclic manner, and would be to regenerate *in situ*, making intermittent process. Calcium chloride has possibility of liquefying Silica gel capable of various secondary reactions, and not unlikely to lose activity. Cooling of reaction bed very difficult, therefore reagent must be highly absorbent ; this implies exacting regeneration stage.

SALT SOLUTIONS : (Calcium chloride). Limited to absorption of about 65 per cent unless cooling conditions better than normal. Cheap and easily obtained. Solution high in water content, regeneration very flexible. Viscosity low, good condition for absorption and heat transfer. Non-corrosive as thus used. Other salt solutions correspond in varying degrees

GLYCERIN : Fluid at all concentrations, but highly viscous in effective range for dehydration Range of compositions available very limited, therefore regeneration exacting, particularly if process attempted without cooling. High viscosity causes low transfer coefficients in absorption and cooling. Slightly volatile. Relatively expensive

The following are representative costs for the compression, refrigeration and absorption processes. They are based on installations of one million cu. ft. per day maximum capacity, and a humidity of 40 per cent. in the treated gas is assumed. (The refrigeration plant, however, as pointed out, will not give this result except when handling gas at fairly high initial temperatures.)

	Compression	Refrigeration	Absorption by calcium chloride
Cost of Plant, Foundations, etc., (no duplication of equipment allowed for)	£1,600	£1,400	£1,500
Power consumption, kW ...	60	10	2·5
Water consuption per mill. cu. ft.	20,000 gals.	4,000 gals.	9,000 gals.

[30] Inst of Gas Engineers. *Gas W.*, April 7, 1928.

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ZUSAMMENFASSUNG

Das Kühlen von Rohgas mittels Luft allein ist eine unsichere Methode und heutzutage für praktische Zwecke veraltet. Die moderne Praxis verwendet hiezu gewöhnlich Wasserröhren-Kondensatoren. Es werden Zahlenangaben gemacht über den bei Horizontalröhren-Kondensatoren erhältlichen Wärmeübergang. Der Waschkühler, bei welchem das zu kühlende Gas in direkten Kontakt mit der kühlenden Flüssigkeit gebracht wird, ist in Amerika gebräuchlich. Ein direkter Kühler-Typus wird im direkten System der Ammoniak-Gewinnung verwendet, wobei durch eine leere Säule ein kräftiger Kaltwasserstrahl abwärts gespritzt wird.

Bei der Teerextraktion beruht das verbreitetste Verfahren darauf, den Dichtigkeitsunterschied zwischen den Teertropfen und dem Gas zur Abscheidung zu benutzen. Der bekannteste Apparat ist wohl derjenige von Pelouze und Audouin.

Interessant und verhältnismässig neu ist die Anwendung des elektrischen Hochspannungsfeldes zum Niederschlagen von Teernebeln. Bei der Konstruktion von Ammoniak-Waschern ist das Wichtigste, höchste Extraktion bei geringstem Verbrauch von Extrawasser zu erreichen. Es werden verschiedene Waschsysteme und die erreichbaren Vervollkommnungsgrenzen besprochen.

Die Anwendungsmöglichkeiten des Säureverfahrens werden entwickelt.

Die geschichtliche und technische Seite des Gastrocknens wird ausführlich beschrieben Die relativen Vorteile der auf Kompression, Abkühlung, Absorption und Adsorption beruhenden Methoden werden besprochen und Einzelheiten über die Betriebskosten angegeben. Der Verfasser ist der Ansicht, dass das Verfahren, bei welchem eine Lösung von Kalziumchlorid zur Anwendung kommt, für die englischen Verhältnisse das geeignetste sei.

COKE OVEN PRACTICE AND DEVELOPMENTS IN BULK CARBONISATION

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

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*Paper No. H*10

CONTENTS

INTRODUCTION

The industries which make up the material side of our civilisation are devoted in large part to improving and increasing the form value of the raw materials furnished us by nature. A familiar instance is the pound of steel, worth perhaps a cent and a half, which has increased in form value something over fifty thousand times when it has been fabricated into hair springs for watches. Among the fuels, the refining of petroleum is a notable instance of the great increase in value resulting from the application of able and costly research, looking to the production of derivatives having higher form values.

It is remarkable that coal, one of the most widely used of the raw materials in our industrial life, has been employed so largely in its original form. In the production of power from coal, nearly all the research and invention has been directed to its more efficient use in the raw state rather than in endeavours to improve the form value of the coal itself, and by treatment, as in the fractionation of petroleum, for example, to so separate or modify the various constituents of the coal as to obtain the greatest potential value. We would surely make an important economic step if by processing coal in an efficient way the form value could be improved, or derivatives could be obtained from it of sufficient

value to pay for the processing, leaving as residue a better fuel than the original coal.

In one branch of the coal industry and practically only one, this result has been secured with notable success. I refer to the manufacture of coke, which employs many millions of capital and some of the best engineering and administrative talent that can be secured.

HISTORICAL

This industry has attained a very respectable age. In the early records of the smelting of metals from their ores, we find references to the "burning" of coal in heaps or meilers to make it better suited for use in the crude furnaces of those days. Even the by-product coke oven has its place in those early records. In 1771, Goethe found one Stauf, "philosophus per ignem," near Saarbrucken, endeavouring in his "connected row of furnaces" to "cleanse the coal from sulphur for use in iron works" and "also turn the oil and resin to account, not even losing the soot." But Goethe relates that "all failed together on account of the many ends in view." Since then many failures have paved the way to the firmly established coking industry of to-day.

In the earlier days of the industry in America, as elsewhere, the beehive oven was universally employed in the production of coke, and the product was consumed almost entirely in blast furnaces, foundries, and other smelting operations. Coal from the Connellsville district, near Pittsburgh, Pa., was the best adapted to the beehive process and was the standard which other fields aimed to equal, just as the coal from the Durham field was famous in Great Britain. Connellsville coke was the standard for all blast furnace operations and its silvery lustre and strong physical structure were highly regarded. This coke ordinarily carried about 12 per cent. ash. The ash was thought to add strength to resist the attrition of the coke in the furnace shaft.

The first plant of by-product coke ovens in America was erected at Syracuse, N.Y., by the Solvay Process Company, in 1893, primarily to produce coke and ammonia liquor for use in the manufacture of alkali. This plant consisted originally of twelve ovens having a capacity of 4.4 net tons of coal per oven charge.[1] All of the tile forming the horizontal flue structure peculiar to this

[1] All tons referred to are American net tons of 2,000 lb. All gallons have volume of 8.33 lb. water.

type was imported from Belgium, as it was thought that no suitable material was available in this country. Within a few years this plant was enlarged to 25 ovens. In 1896, another plant of the same type was built at Dunbar, Pa., at about the same time that a plant of Otto Hoffman ovens was built for the Cambria Steel Company at Johnstown, Pa. Both these plants produced coke for blast furnace use. There was, however, great prejudice against by-product coke, and furnace men were quite sure that coke without the familiar silvery glaze could not make a satisfactory blast-furnace fuel. This prejudice was widespread and provocative of endless arguments. It was thought to be entirely unsuitable for foundry cupola work on account of its small size as compared with the product of the 72 hours beehive coking. However, the economic advantages of the by-product ovens are so important that the iron masters' prejudices against the coke were slowly overcome, and after about ten years from the starting of the first ovens the by-product coke industry began to grow rapidly.

The use of silica brick in oven contruction was introduced practically simultaneously by several builders in 1905 and 1906, and its resistance to high temperature, its better conductivity, and its greater capacity for maintaining its strength as it approached the melting point, rapidly brought silica brick into general use for oven construction. Many problems had to be solved in oven design on account of its relatively large expansion under working temperatures, but it soon proved its superiority. Silica brick was not adopted in European practice for a number of years after it was in general use in America.

In 1919 the production of coke from by-product ovens passed, for the first time, the beehive output. The figures were 25,138,000 net tons from the by-product ovens and 19,000,000 net tons from the beehive plants. At present the ratio is about 80 per cent. for the by-product ovens and 20 per cent. for the beehive. The output from the beehive plants now in operation varies greatly from month to month with the fluctuations in total demand, since the operation of the by-product plants must be kept, if possible, reasonably uniform on account of operative conditions, whereas the beehive plants may be put into or out of run without difficulty. In May of this year 4,460,000 tons of coke were produced, of which 91.6 per cent. was made in by-product ovens. This tonnage represents an increase of 16 per cent. over the seven year average

production. Very few new plants of beehive ovens have been built in America for a number of years, and it has been suggested that the beehive in America is becoming the flywheel of the coking industry.

Oven Capacity: Coking Time

The growth of the coking industry in America, since the early days when the attention of the operators was concentrated mainly on the adaptation to American conditions, was primarily in the increasing of the capacity of the units and the reduction of capital and other operating charges per unit of product. This was accomplished in three ways, by enlarging the cubic capacity of the ovens, by shortening the coking time, and by increasing the number of ovens served by one crew of operators, through the use of labour-saving machinery.

The first plant of 12 by-product ovens referred to above was soon enlarged to 25. This was regarded as an economical unit, as all the crew were fully employed. It had a capacity for coking 110 short tons of coal per day. The coking time was at the rate of $\frac{2}{3}$ in. per hour. Each oven held a charge of 4.4 net tons. The oven capacities were rapidly enlarged, the introduction of silica brick permitted a great reduction in the coking time of each charge, and a thorough development of electrically operated machinery to every step in the operation of the ovens has increased the capacity of the typical oven block from 110 tons to 1,500 to 1,800 tons per day. The largest ovens now operating in America have a capacity of 19 to 20 tons per charge. (Considerably larger ovens are now under construction in Germany.) The oven blocks have been increased to contain as many as 60 ovens instead of 25, as first adopted, and the coking time has been greatly reduced; one inch per hour is regarded as a very moderate speed. One plant has a record of two months' operation at more than 1.3 inches per hour, or double the earlier rate. This increase per unit of plant capacity and per man hour has to a large extent off-set the greatly increased cost of construction and wage rate since the early days of the industry.

Coal Mixture

Coke-oven engineers have not been satisfied, however, with the mere increase of capacity of their plants. Unlike the usual practice in Europe, American coking plants are in most cases located at or near the point of consumption of the coke, instead of

at the coal mine. This practice has encouraged the use of a mixture of coals to produce a coke of chemical and physical quality superior to what could be produced from any one coal. In some few cases three or even four different coals are mixed to form the oven charge. The general practice of mixing two or more kinds of coal has greatly improved the quality of coke, especially as to its physical structure. Many of our purest coals, when coked alone, do not produce a coke of satisfactory structure for metallurgical use, but a suitable mixture, coupled with the application of coking temperatures adapted to the coals, has resulted in a high average of coke quality throughout the country. In some cases foundry coke produced from a well-selected coal mixture secures a price as much as $3.00 per ton over competitive cokes produced by old methods. Recently, careful research has shown very promising indications looking to the selection for a mixture of coals which have about the same fusion point, instead of selecting them by their proximate analyses or their price. These experiments indicate that when two coals having about the same fusion point are mixed for the coking process, a more uniform coke structure, freer from cross checks and irregularities, is secured.[2]

Some experiments have been made on a works scale in which, instead of employing a mixture of high and low volatile coals for an improved coke structure, the char produced by treating a portion of the high volatile coal by low-temperature distillation is substituted for the low volatile portion of the mixture. The results were promising, but perhaps not commercially important in this country, since in most places where coke is made supplies of both high and low volatile coal can readily be obtained. These experiments followed in general the method worked out by Dr. Kotaro Shimomura, of Kyoto, Japan, who has been able to produce metallurgical coke of good structure from the only coals available for his plant, which average about 42 per cent. in volatile matter, producing, when untreated, a soft friable coke unsuited to metallurgical use.

Free-Burning Cellular Coke

One of the characteristics of recent coke-oven operation in the manufacture of blast furnace coke is the production of a free

[2] See paper by F. F. Marquard, read before American Iron and Steel Institute, May 25, 1928.

burning coke having a well-developed cell structure, more reactive to the oxygen of the blast than was formerly thought practicable. The large crucibles and steep bosh walls of the modern American furnaces have made the use of these more reactive cokes practicable, and permitted the use of many coals heretofore thought undesirable. In this practice it is usually desirable to finish the coke at a temperature of about 1,100°C.

Collection of Gas

In the recovery of the by-products from the carbonisation of coal, great improvements have been made since the practice of earlier days. A notable one, now generally adopted, is the treatment of the gases in the collector main, where the gases are brought together from the several ovens. Formerly this collector main, corresponding to the hydraulic main of the old gas works, was a constant trouble maker, and considerable labour was required to keep it clean from the deposits of soot and heavy tar. A circulation of tar was formerly maintained through this main, and in some cases mechanically operated scrapers were employed which, by their slow movement through the main, helped to prevent accumulations. The present practice is to circulate no tar through this main, but to employ sprays of the liquor condensed from the gas. These sprays are introduced not only into the collector main itself, often between each oven or every other oven, but also on the valves employed to shut off the individual ovens from the main. These sprays not only wash the surfaces but also immediately bring the temperature of the gases down to about 80°C., thus preventing the formation and accumulation of heavy pitch. When properly applied, this plan removes all manual labour required for cleaning the collector main or the pipe connecting it with the condensing apparatus. The amount of this circulation, for the best results, averages about 45 gallons per hour, per ton of coal coked per day.

Smoke Prevention

A recent improvement is the elimination of all smoke in charging the oven. As ordinarily operated, large quantities of smoke and rich gas are released into the atmosphere during the charging period, but as coking plants are introduced into thickly built up sections, or even into the hearts of the towns or cities, as in cases where the coking plants are operated by gas companies, the

production of smoke is seriously objectionable and even forbidden. Several plants have recently been equipped with off-take pipes for the gas at each end of the oven and with only one charging hole. When so equipped, a slight suction is maintained on the off-take pipes by a steam jet, so that all of the gas and smoke generated during the charging period is drawn into the collector mains, and an oven can be charged without setting free any smoke or gas. In practice, this procedure adds a measurable quantity of gas to the total amount produced per ton of coal.

Condensation of Gas

For condensing the gases which, under the methods described above, leave the collector main at a temperature of about 80°C., two types of condensing equipment are employed. The more general one is the tubular condenser consisting of a vertical steel plate cylinder containing steel tubes, through which the cooling water is circulated. The gas passes around the tubes and is so baffled as to insure efficient contact with the cooling surface. This type has the merit of simplicity, but is subject to rather high repairs in cases where the water or gas contains corrosive elements. The other type consists essentially of a similar vertical steel cylinder, but instead of tubes it is filled with grids composed of wooden boards about ⅝ in. thick spaced ¼ in. to ½ in. apart and set on edge, each course running in alternate directions. These grids are generously showered with the liquor which has been condensed from the gas, and this liquor is in turn cooled in a series of pipe coils arranged in banks adjacent to the condenser. This liquor is circulated again and again, through the condenser and back to the coils. Any accumulation of liquor and tar is separated in a large decanter whence they are pumped to the ammonia still and the tar storage tank. By a proper control of temperatures, nearly all the free ammonia can be kept in the gas, thereby reducing much of the work in the ammonia still.

Ammonia

In the early days of the industry, most of the ammonia was recovered as a crude liquor. Later, some of the operators developed a very simple method of producing pure aqua ammonia directly from the gas liquor at one operation. Partially purified ammonia liquor was also produced for certain industries, such as explosives and in the production of cyanides. The market for high-grade ammonia has now been practically monopolised by the producer

of synthetic ammonia. Nearly all the ammonia produced by coke works is marketed in the form of sulphate of ammonia, produced by what is called the direct process. That is, all of the gas from the distillation of the coal is passed through a bath of weak sulphuric acid, from which the ammonium sulphate is crystallised, centrifuged and washed. The best grades of sulphate are known as "Arcadian," which in practice means that the sulphate is practically neutral as to free sulphuric acid, and that the moisture has been removed by artificial drying.

Benzol and its Homologues

Benzol and its homologues are generally removed from the gas by absorption in a petroleum oil known to the trade as straw oil, instead of using the oil recovered from the distillation of tar, as is generally customary in Europe. Recent developments in apparatus design and operating practice have given very efficient results, both in capacity of apparatus and economy of steam. A large percentage of the benzols produced are a mixture of benzol, toluol, and zylol, known as motor benzol, which is mixed with gasoline for motor fuel. Pure products are also made where market conditions justify. It is generally customary in plants which supply gas for sale in towns and cities to omit the recovery of benzol, since it ordinarily enjoys a higher market value as gas than could be received for the benzols after deducting the cost of recovery.

Disposition of Surplus Gas

An important development in the American coke-oven industry of comparatively recent years is the full utilisation of surplus gas beyond what is required for heating the ovens, which in the best American practice amounts to a little over 1,000 B.Th.U. per pound of coal. In many plants the value of this gas required for oven heating is quite sufficient to justify the substitution for the coke-oven gas of producer gas, made from the small coke or other fuel, so that the entire gaseous product of the carbonisation is made available for sale.

In 1926, 62 per cent. of all the surplus oven gas produced was used in steel plants or other factories associated with the coke-oven plants. About 20 per cent., approximately 90 billion feet, was distributed through city mains and about 8 per cent. was sold for general industrial uses. The change from candle-power standard for city gas to the calorific standard, which generally

runs from 520 to 540 B.Th.U. per cubic foot, has permitted the operators of coke plants to produce gas that will meet these standards without much preparation except the usual removal of hydrogen sulphide. In fact, many coke plants produce a gas that is rather higher in calorific value than the standard, so that some dilution is required. During recent years coke ovens have been installed by public utility companies in quite a number of places, the capacities of these plants varying from 2,000,000 feet of gas per day, or even less, up to 20,000,000 feet. Gas produced in coke ovens is assuming more and more importance as a source of supply in the gas industry, and the coke oven is well established as a source of coal gas for city use. As is well known, water gas has been for years the principal supply for city and town distribution in America, but in late years many of the public service companies are turning to coal gas. The present situation and the importance of coke-oven gas as a part of the coal gas supply are illustrated by the following figures :—

PRODUCTION OF CITY GAS

	1926	1927
Water gas	252 billion cu. ft.	241 billion cu. ft.
Coal gas manufactured	71 ,,	81 ,,
Coke-oven gas purchased	83 ,,	91 ,,

No figures are available from the gas industry showing the total amount of coke-oven gas used for city distribution, since the statistics include, under the heading "Coal gas made by the utilities," the production of coke-oven gas from plants owned by the utilities as well as that from other types of apparatus.

In the early days of the coke-oven industry, a number of plants which furnished gas to the public service companies found it necessary, in order to meet specifications, to separate the richer fraction of the gas coming off during the early part of the coking operation from the leaner part which contained larger percentages of hydrogen and carbon monoxide. Modern methods, insuring better control of the operations and better selections of coals make this no longer necessary, as the average of the gas, if the benzols have not been removed, often runs 600 B.Th.U. per foot or more.

Purification of Gas

The introduction of the so-called liquid purification processes for the removal of hydrogen sulphide from the gas has been a

notable step forward in the technique of gas purification. As originally operated, this consisted in merely scrubbing the gas with a solution of sodium carbonate, the gas passing upward through a cylinder filled with wooden grids, as described above, the soda solution being showered from the top. In the absorption of the hydrogen sulphide, sodium thio-sulphate is formed, together with some sodium thio-cyanate. This fouled soda solution is revivified by showering it through a second grid-filled cylinder, through which a large volume of air is pumped up against the current of liquid. By this revivification most of the sodium carbonate is made active again, so that the solution is continued in use with only a small addition of fresh sodium carbonate from time to time. This process is particularly useful where there is insufficient room for the ordinary oxide purifying boxes, or where the sulphur in the raw gas is high. In the revivifying operation large quantities of hydrogen sulphide are driven off into the atmosphere, which, under some conditions, is objectionable, and limits the use of the process. Moreover, the process does not remove all of the hydrogen sulphide, so that a catch box containing the usual oxide of iron is required to remove the last traces. A material improvement in this process has recently been developed and is now in successful commercial use at several plants in which the contaminated soda solution is revivified by a mineral catalyst with the deposition of the sulphur in a practically pure and very highly divided form. Experiments now under way indicate that this sulphur will have a wide use in the arts as an insecticide and for other similar uses. If these markets can be secured it appears that the returns from the sale of the sulphur will more than balance the entire cost of the purifying operation. With no market for the sulphur the costs are somewhat higher than for the usual oxide purification.

Dehydration of Gas

Another interesting development which has just reached the commercial stage is the dehydration of the gas by a simple process which reduces the gas to a temperature 8° to 10°C. below that of the available cooling water. At summer working temperatures this would mean the removal of nearly one pound of water by condensation per thousand feet of gas treated, a result of wide reaching interest and importance in the distribution of gas, and in many industrial operations.

Domestic Coke

While the production of coke in this country has always been mainly for metallurgical use, a considerable portion has been consumed in other ways and in recent years notably as domestic fuel in competition with anthracite and screened bituminous coal. In 1926, 23.2 per cent. of the total coke produced was consumed for these other uses. During the last few years the growth of sales for domestic use has been rapid. Anthracite is in many respects an ideal fuel for domestic use, since it is entirely free from smoke and is dustless. It has been very generally the only solid domestic fuel employed throughout the districts that are reached from the anthracite regions of eastern Pennsylvania at reasonable transportation cost, and many hundreds of thousands of tons have been carried annually as far as the western end of the Great Lakes during the season of open navigation. During recent years the production cost of anthracite has of necessity risen on account of the greater difficulties in mining, and domestic coke has been found to be a welcome relief to those who found advancing anthracite prices a burden. Many coking plants are selling a considerable portion of their product as domestic coke and nearly all of such plants which are operated primarily for the production of gas for use in cities, dispose of their entire coke product in this market. In earlier days much of the coke produced in gas retorts was sold as domestic fuel, but with little satisfaction, as it was ill-prepared and of poor quality. As the business has developed, it has been found quite essential that coke for domestic use shall be of hard structure and sized very accurately. When properly prepared, domestic coke can be freely sold in almost any locality where anthracite is the familiar fuel, but, partly on account of popular prejudice, the price to the consumer is usually from $1.00 to $2.00 per ton lower than the price of anthracite.

In cities where bituminous coal is the normal domestic fuel, there is almost continued agitation against the smoke which it produces. It has been found that the most difficult problem in the elimination of smoke is the domestic fire. Factories and power plants can burn bituminous fuel without the production of smoke and oftentimes with greater economy.

Properly prepared coke seems at the present time to be the most effective remedy for the smoke evil in cities and towns which are distant from the anthracite fields. Briquettes that have been made

smokeless by baking and the char from the low-temperature distillation of coal, may aid in the campaign when they have become commercially established.

STATISTICAL SUMMARY OF THE COKE INDUSTRY IN THE UNITED STATES IN 1926

From U.S. Bureau of Mines

	By-product.	Beehive.	Total.
Coke produced:			
Quantity ... ... net tons	44,376,586	12,488,951	56,865,537
Value	$250,748,533	$57,024,869	$307,773,402
Screenings and breeze produced:			
Quantity ... ... net tons	4,183,453	218,342	4,401,795
Value	$9,233,229	$648,193	$9,881,422
Coal charged into ovens:			
Quantity ... ... net tons	63,646,610	19,224,500	82,871,110
Value	$247,170,284	$38,541,691	$285,711,975
Average value	$3·88	$2·00	$3·45
Average yield in per cent. of coal charged:			
Coke	69·7%	65·0%	68·6%
Breeze (at plants actually recovering)	6·6%	2·8%	6·2%
Ovens.			
In existence, Jan. 1	11,290	57,587	68,877
In existence, Dec. 31	11,716	52,558	64,274
Dismantled during year ...	183	5,018	5,201
In course of const., Dec. 31 ...	978	—	978
Coke used by operator in blast furnace or affiliated works:			
Quantity .. ... net tons	31,334,305	1,575,039	32,909,344
Value	$160,606,129	$7,148,961	$167,755,090
Disposal of Coke:			
Sold for furnace use to affiliated corporations—			
Quantity ... net tons	2,127,176	4,260,028	6,387,204
Value	$10,955,119	$20,306,453	$31,261,572
Merchant sales of furnace coke—			
Quantity ... net tons	1,566,980	4,156,032	5,723,012
Value	$9,800,299	$16,384,006	$26,184,305
Sold for foundry use—			
Quantity ... net tons	2,168,017	1,163,660	3,331,677
Value	$16,836,376	5,967,936	$22,804,312
Sold for domestic use—			
Quantity ... net tons	5,056,568	386,045	5,442,613
Value	$37,567,659	$2,677,741	$40,245,400
Sold for industrial and other use—			
Quantity ... net tons	1,662,837	963,797	2,626,634
Value	$12,285,212	$4,638,542	$16,923,754

BY-PRODUCTS OBTAINED FROM COKE-OVEN OPERATIONS IN 1926

Product.	Unit.	Production.	Sales. Quantity.	Value (Dollars). Total.	Value (Dollars). Average.
Tar	Gal.	529,486,374	277,248,522	14,103,760	0·051
Ammonia:					
Sulphate	Lbs.	1,167,859,453	1,152,141,717	24,658,031	·021
Ammonia liquor (NH_3 content)	,,	53,523,229	53,448,034	3,470,172	·065
		—	—	28,128,203	—
Sulphate equivalent of all forms	,,	1,381,952,369	1,365,933,751	—	—
Gas:					
Used under boilers, etc.	M. cu. ft.	[1]706,681,828	25,953,876	1,438,699	·055
Used in steel or affiliated plants...	M. cu. ft.		249,840,649	27,955,574	·112
Distributed through city mains	M. cu. ft.		89,565,953	29,978,997	·335
Sold for industrial use...	M. cu. ft.		32,553,610	5,313,530	·163
			397,914,088	64,686,800	·163
Light oil and derivatives:					
Crude light oil	Gal.	[2]164,059,552	10,783,568	1,330,208	·123
Benzol, crude	,,	4,744,713	4,660,621	1,109,974	·238
,, refined... ...	,,	17,713,904	17,327,169	3,957,719	·228
Motor benzol	,,	90,029,972	89,501,212	16,863,109	·188
Toluol, crude	,,	432,317	400,308	127,298	·318
,, refined	,,	8,359,135	8,250,297	2,787,454	·338
Solvent naphtha ...	,,	4,704,555	3,546,117	1,035,870	·292
Other light oil products	,,	4,127,710	1,324,303	93,344	·070
		[3]130,112,306	135,793,595	27,304,976	·201
Naphthalene:					
Crude	Lbs.	7,746,821	7,556,372	96,210	·013
Refined	,,	139,701	166,851	1,100	·007
		7,886,522	7,723,223	97,310	·013
Other products		—	—	148,720	
Value of all by-products sold		—	—	[4]134,469,769	

[1] Includes gas wasted and gas used for heating retorts.
[2] Refined on the premises to make the derived products shown, 159,589,756 gal.
[3] Total gallons of derived products. [4] Exclusive of value of breeze production.

RÉSUMÉ

Ce mémoire se compose d'un résumé du progrès fait par l'industrie du coke en Amérique et de son agrandissement et de son développement jusqu'à présent. Il décrit les premières installations du four à récupération des sous-produits en Amérique et dépeint leur agrandissement aux points de vue de la capacité, de la mécanique et du rendement. Il dépeint les méthodes adoptées

pour obtenir un coke de meilleure qualité, pour la meilleure utilisation des mélanges de charbons de différentes espèces, et pour le choix de charbons convenables pour ces mélanges fait selon des essais au laboratoire, y compris la détermination du point de fusion et des portions résineuses de la houille. Il considère le rapport en Amérique entre l'ancien four à ruche, utilisé encore, et le four à récuperation des sous-produits ainsi que l'importance de celui-là jusqu'à présent dans la métallurgie. Il dépeint l'emploi du coke dans les domiciles, emploi qui croît avec rapidité à présent, et les conditions qui ont donné lieu à cet accroissement.

Il dépeint les perfectionnements apportés dans la récupération des sous-produits et l'importance de ces sous-produits dans la vie industrielle de l'Amérique. Une application importante de l'opération de carbonisation consiste en l'utilisation du four à coke en premier lieu pour la production de gaz pour les domiciles et les établissements industriels des villes. Ce mémoire expose ce développement du commencement, en considérant les problèmes rencontrés et résolus et l'importance actuelle de cette source de gaz en Amérique.

Des tableaux statistiques donnent les qualités et les valeurs de quelques produits de cette industrie et leur application aux arts.

COAL CARBONISATION IN JAPAN

IMPERIAL FUEL RESEARCH INSTITUTE

YOSHIKIYO OSHIMA

Paper No. H11

CONTENTS

In this short paper the author intends to describe some of the researches conducted in connection with the carbonisation of Japanese coal, particularly in regard to the reactivity of coke and semi-coke, carried out at the Imperial Fuel Research Institute.

HISTORICAL

If the standard of coal for use in the making of a good coke, as cited in many publications, holds good, it is not an exaggeration to state that no such coal is produced in Japan. The Japanese coke industry, it must be admitted, relies for support on some Chinese coal. As almost all the coal in Japan is of tertiary formation, its volatile content is fairly high, nearly 40 per cent. on the average and sometimes more, and it swells and expands a great deal during carbonisation, producing a fingery coke with undesirable features. The fuel ratio, often meaninglessly referred to, is small, averaging below two. Moreover, most Japanese coal contains a large amount of mineral matter, ordinarily more than 10 per cent., and the coke produced contains a high percentage of ash accordingly. Sulphur is another factor to be considered, and one which is not favourable, except in a few varieties. The Miike coal, which is the best coking coal, for example, contains more than 2 per cent. of sulphur.

The Japanese coke industry was started with the beehive oven, and then the by-product system was introduced, as it has been in other countries. In the early days home coal alone was used, but later it was found that a mixture with a certain Chinese coal made a better coke than the straight coal. The following table will show the quantity and varieties of coal used in this industry (in 1,000 tons) :—

	1922	1923	1924	1925
Kyushu coal	1.026	1.053	1.111	1.239
Hokkaido coal ...	165	204	241	332
Chinese coal	363	420	480	393
Indo-China coal ...	23	21	21	22
Others	26	26	39	24
Total ...	1.580	1.724	1.892	2.010

The modern theory of coking coal is introducing certain modifications in coke oven design. The coke industry in this Empire has been developed somewhat differently from that in other countries. It may not be an error to state that the "latest type" was given rather important consideration when selecting the oven at the start of the industry, rather than considering the nature of the coal, or in other words, it was thought a simple matter to produce a good coke from Japanese coal without knowing its properties. In accordance with the progress of coal research in this country, the coke manufacturers were awakened to the necessity of examining the conditions of the oven and of studying the properties of their product.

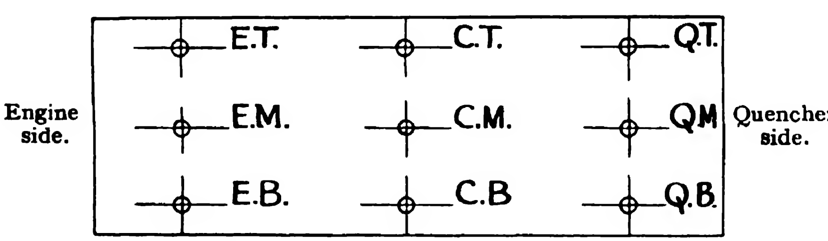
The first step was an improvement in the heating flues of Koppers type oven at the Imperial Steel Works, Yawata. Mr. Kuroda constructed a new type of heating flue, and his system is now being used not only at the Imperial Steel Works but also by many other companies.

The second step forward was the patented process and apparatus of Dr. Shimomura, which is also being used at the Osaka Gas Company. The former has for its object the construction of an oven to minimise the coking time and improve the coke property, though the charge consists of a mixture of Japanese coal blended with certain Chinese coal; while the latter is a new process of making good coke with home coal only. The principle of the Shimomura process consists of treating highly volatile coal at a temperature between 400° and 600°C., in mixing semi-coke so

produced, called X-coal, in a suitable proportion to raw coal, and in carbonising the mixture in the coke oven as is usually done. He claims that there is no need to blend prior to carbonisation, as is usually required, and it is applicable to non-caking coal as well.

Reactivity of Coke

The third, the most recent, step forward is the study of the nature of coke, which should be considered from the point of view of its manufacture and its use. The Imperial Fuel Research Institute took up the problem of the reactivity of coke in 1925, and has called the special attention of coke manufacturers to this interesting proposition. The reactivity is defined here as the reducibility of CO_2 into CO by coke at 900°C. and at a different rate of CO_2 flow, that is the rate of reduction of CO_2 according to time of contact between the gas and the coke at 900°C. Varieties of metallurgical and foundry cokes and semi-coke have been tested to ascertain the relations between the reactivity and the structure of the coke. It will be interesting to show the result of samples taken at a definite position in the oven. The pilot samples were taken at nine different points in an oven as shown in the figure below :—



E—Engine side. C—Centre. Q—Quencher side.
T—Top. M—Middle. B—Bottom.

Fig. 1.

Each sample was ground so as to pass a five-mesh and remain on a ten-mesh sieve, and ten grams of it were taken as a test sample. The reaction tube was made of transparent silica, in the centre of which the sample was placed and heated up to 900°C. During that time CO_2 was slowly passed. Keeping the temperature at this point, the dried and purified CO_2 gas was passed into the tube at a definite flow. CO content in the exit gas varied at the beginning of the test, but it soon nearly reached constant, when

the gas was analysed every ten minutes. The time of contact was calculated by the following formula :—

$$T=(A\times L-W/S)\div F.$$

where A, sectional area of the reaction tube,
L, length of the coke sample in the tube,
W, weight of coke in the tube,
S, apparent specific gravity of the sample,
and F, rate of CO_2 flow in cc. per second at NTP.

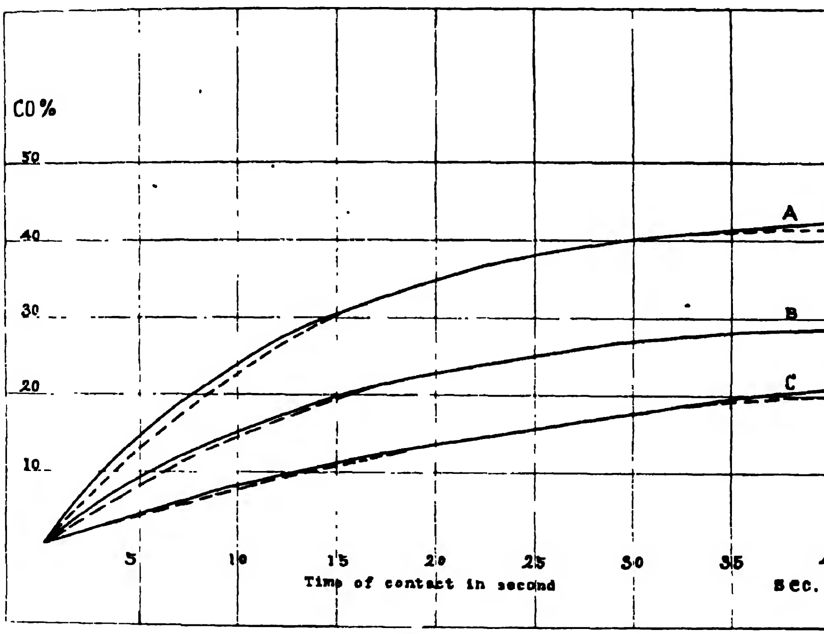


Fig. 2

The amount of CO produced was checked by finding the reaction constants k_1 and k_2 according to the equations of Dr. Clement, and it was found that the values, calculated and found, nearly coincided. Fig. 2 shows the results of three different samples, in which A is foundry coke while B and C are blast furnace coke, and the full-lined curves are the results found, the dotted lines representing those calculated.

Figs. 3 and 4 show the results of a pilot samples of different types of ovens. .

If it is assumed that the pilot samples represent the conditions around the point where the sample was taken and the reactivity

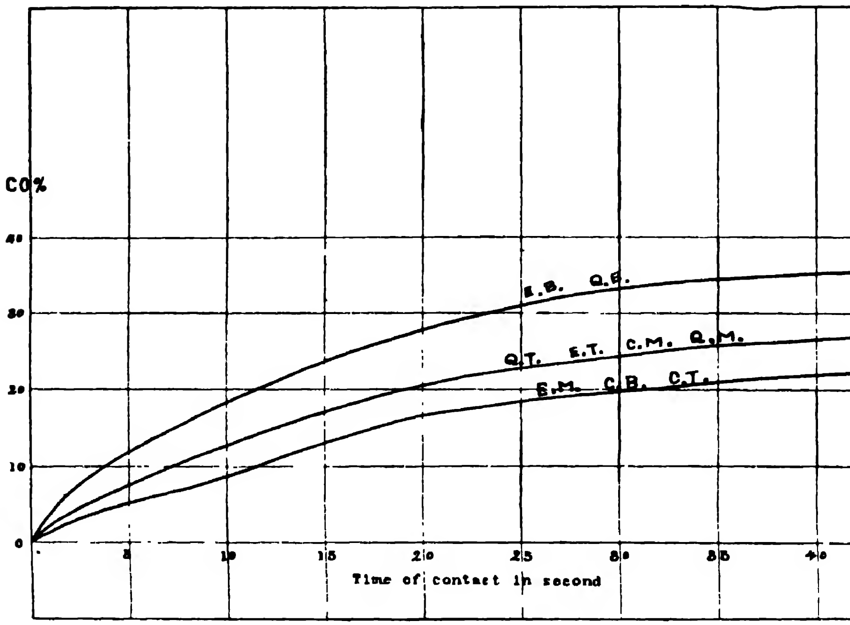

CO%
40
30
20
10
0
5
10
15
20
25
30
35
40
Time of contact in second
E.B. Q.E.
Q.T. E.T. C.M. Q.M.
E.M. C.B. C.T.

Fig. 3.

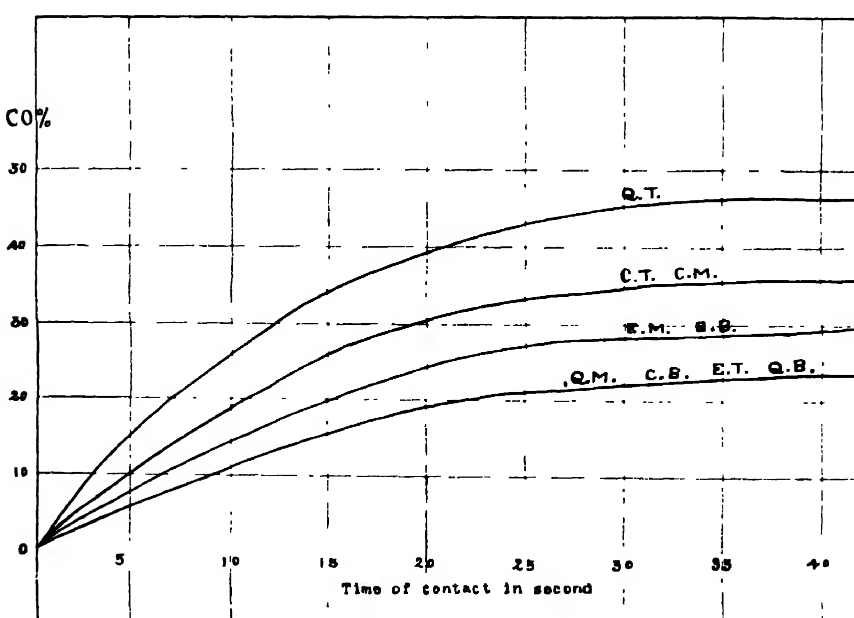

CO%
50
40
30
20
10
0
5
10
15
20
25
30
35
40
Time of contact in second
Q.T.
C.T. C.M.
E.M. E.B.
Q.M. C.B. E.T. Q.B.

Fig. 4.

is classified into three convenient grades, then the figures given below can be obtained.

These show what the conditions of carbonisation are in the oven. The samples taken right below the off-take pipe always show poor reactivity. The coke at this point on the one hand has always a higher volatile content than the other parts, as condensation and distillation of the tar vapours are repeatedly performed, and on the other hand the gaseous products are brought there and some of them are decomposed, forming graphitic carbon. These will be the main reasons for the poor reactivity of the coke found there.

The figures quoted may also serve to lead to the discovery of the path of the gas or the progress of carbonisation, and the difference between horizontal and vertical heating flues.

In this paper it is not proposed to discuss the relations between the reactivity and porosity, but two points are to be noted.

	B	C	B	
QS	C	B	B	QS
	A	C	A	

Fig. 5.

C	B	A	
B	B	C	QS
B	C	C	

Fig. 6.

Porosity of Coke

1. The porosity of coke is one of the important factors which distinguishes the different natures of the three principal classes of coke, *i.e.*, foundry, metallurgical and blast furnace. So far as the samples examined are concerned, the porosity is about 40 per cent. for the first, 30 to 35 per cent. for the second and 20 to 30 per cent. for the third.

2. The content of volatile matter has been much discussed by many authors in connection with reactivity. The volatile matter is defined as the weight decrease when a sample is heated at a definite temperature, usually 900°C., while nothing has ever been said about the nature of it. As coke has a porous structure it may adsorb gases and vapours when it is exposed to the atmosphere.

The author determined the moisture and the volatile matter in coke under different methods of preparation, namely :—

1. Air-dried sample;
2. No. 1 sample, but exposed to the atmosphere for twenty-four hours after the determination of moisture and volatile matter;
3. The same air-dried sample as No. 1, but exposed to the atmosphere for twenty-four hours after preparation;
4. The same air-dried sample as No. 1, but soaked in water and air-dried again.

The results were as follows :—

TABLE I.

		Sample A.		Sample B.	
		1	2	1	2
1	Moisture	0.18	0.21	0.60	0.64
	Vol. matter ...	1.29	0.65	2.10	1.85
2	Moisture	0.14	0.43	0.69	0.78
	Vol. matter ...	1.38	0.93	1.71	2.23
3	Moisture	0.18	0.41	0.81	0.89
	Vol. matter ...	1.10	0.58	1.94	1.95
4	Moisture	0.25	0.56	0.86	0.75
	Vol. matter ...	1.48	1.46	2.41	2.28

(1 and 2 are under different humidity conditions.)

It may, therefore, be understood that coke adsorbs moisture which is not completely driven off at 105° to 110°C., but remains at a higher temperature, and may be determined as volatile matter. Volatile matter in coke, consequently, is not the same as that in coal, but mostly moisture adsorbed or occluded, and a part of it is eliminated near 110°C., while some of it can only be driven off at an even higher temperature. This is naturally due to the surface structure, and it is, accordingly, correct to say that the reactivity is influenced by surface conditions, porosity and the state of carbon which govern the adsorption, but not the content of so-called volatile matter. The porosity in these experiments was calculated by the usual method, that is, the ratio of real to apparent specific gravity, but it is not real porosity in the scientific meaning of the word, though it may be used as an approximate figure. The author wishes to reserve further data on this theme, as a new method of determining the real porosity is in course of preparation.

According to the results mentioned above, the Imperial Fuel Research Institute is now conducting experiments in regard to the improvement of coke manufacture, particularly from the point of view of proper carbonising conditions for Japanese coal without blending and oven construction to suit it.

Low-Temperature Carbonisation

Though this is rather a young branch of the carbonisation industry in this Empire, it lies on the right road to progress. A crude method of low-temperature carbonisation has been operated successfully for a long time at Fukuoka, Kyushu, which aims at producing a smokeless domestic fuel, but up to the present no attention has been paid to low-temperature tar. The process is a sort of self-carbonisation where the necessary heat is supplied by burning a part of the charge. It is not like the beehive system, as there is no oven constructed, but a heap of coal is first formed, and the fire is then started, new coal being added gradually to maintain a proper fire in the heap. When carbonisation has properly proceeded, judged by experience, the heap is covered with sand or clay and left overnight until it cools down. The product so obtained contains 10 to 15 per cent. volatile matter and burns very freely without smoke, the kindling temperature being near 300°C. Special coal of low sulphur content is used in this process, and it is still working on a profitable basis, producing about 20,000 tons annually.

Modern improved retorts with tar recovery are also working, among them the Tozer and Davidson systems from England, all of them being of the stationary vertical and intermittent type, while the experimental plant at the Imperial Fuel Research Institute is of the continuous type with steaming device. The retort is about the same in construction as the E-type used by the Fuel Research Board in England, but it was quite independently developed here. When a short report on the latter was published, the tests with the former were nearing conclusion.

It was said formerly that semi-coke is an ideal domestic fuel, as is maintained in other countries, and that a greater part of the charcoal, which is the most popular fuel throughout this country, should be replaced by this new product. But in this field it must be remembered that a big market for semi-coke has not yet been developed, although it is finding a favourable field in industrial circles, particularly in the preparation of tea, biscuit baking

and silk-worm culture. Briquettes of semi-coke breeze are also most popular among housewives. The future for semi-coke in this country is said to be an industrial problem, as the specification for domestic fuel is very complicated, and it is difficult to produce a hard and compact block of semi-coke from most of the Japanese coal. Fragility of semi-coke and breeze once formed the subject of a heated discussion with regard to market prospects, but they are not so much discussed these days as is pulverised coal firing, which is much favoured among power station engineers.

Low-Temperature Tar as Fuel Oil

The properties and application of low-temperature tar have been

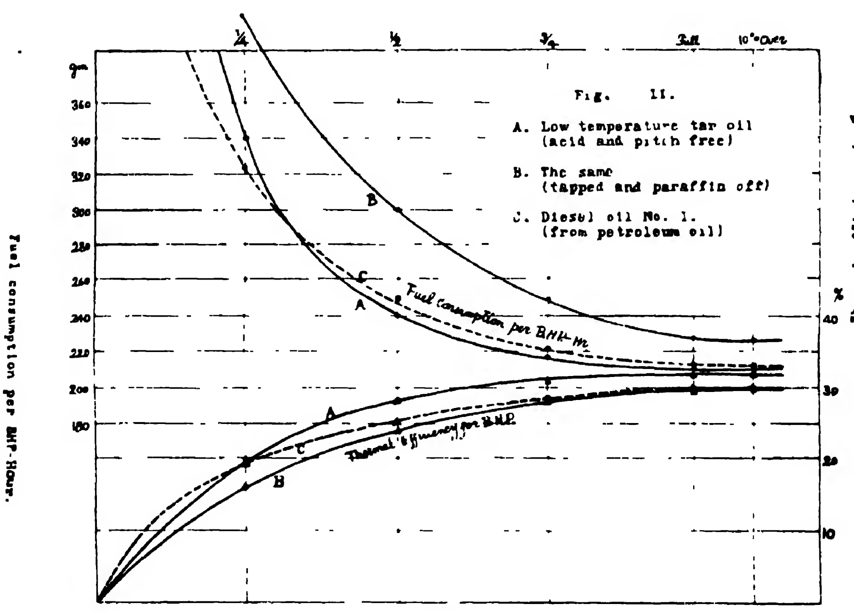


Fig. 7.

much studied at the Imperial Fuel Research Institute, and according to tests applied to a 33-h.p. Diesel engine at the Institute it has been proved that the oil can be used equally with those produced from petroleum, and acid-free tar oil is far better for the purpose indicated. The accompanying figure (7) will show the comparative results from these oils.

A new method of eliminating the acid part from low-temperature tar oil has been discovered at the Institute. It consists of using alcohol of a definite concentration according to the nature of

the tar. This process is very satisfactory and economical, as no expensive alkali and acid are needed, but the solvent can be easily and completely recovered by a single distillation.

Impregnation tests on railroad sleepers were carried out at the Imperial Railways Experimental Station, and it was proved that the low-temperature tar oil is superior to creosote oil, both from the point of view of disinfection and of water-proofing.

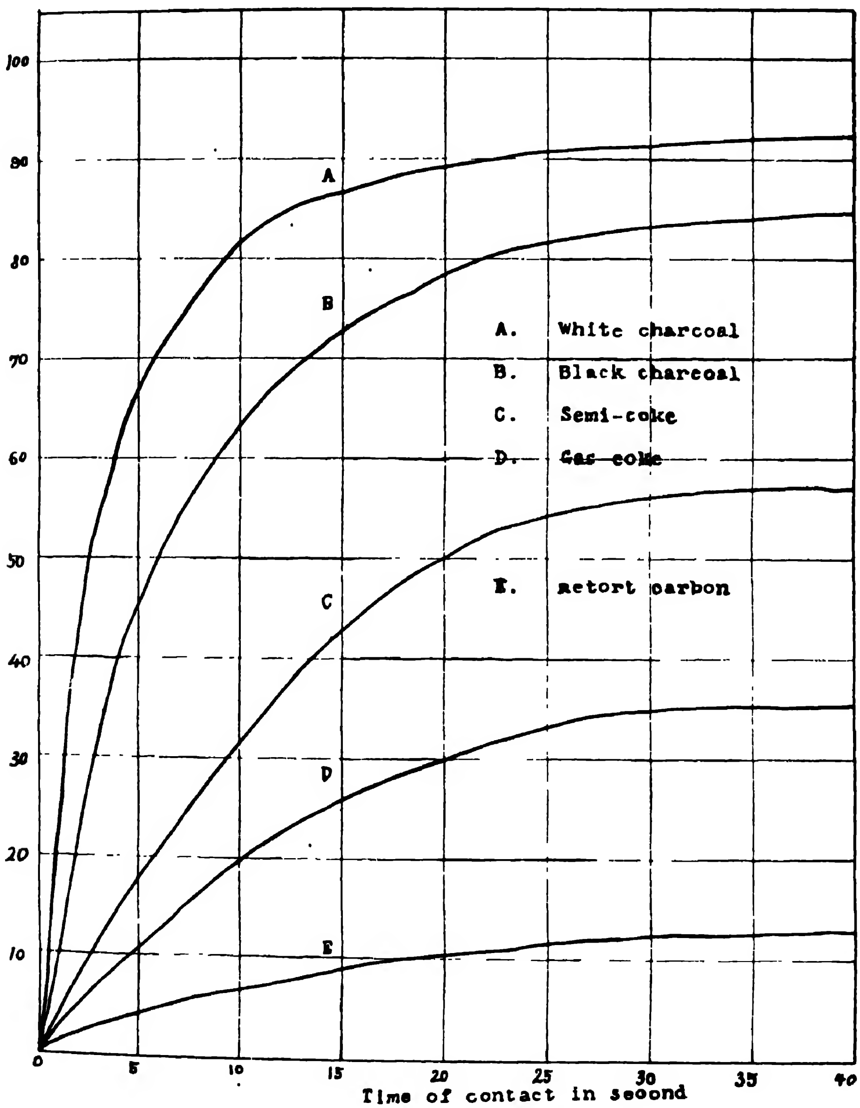


Fig. 8.

Reactivity of Low-Temperature Coke

It may be interesting to add here again a few lines regarding the reactivity of semi-coke and gas coke, as compared with that of charcoal. The results obtained at the Imperial Fuel Research Institute, the method employed being similar to that given previously, are shown in Fig. 8 (on previous page).

These results show that the reactivity of coke not only depends on the state of carbon but also on structural difference. These are very important in relation to the improvement of Japanese domestic fuel, because most of the house furnaces in use here do not possess a chimney and function under a slow draught. Charcoal, as in the past, will be the best fuel for such furnaces, but users may not be anxious to continue to use it because of its increasing price. The briquette of semi-coke or carbonised briquette, functioning at a low temperature, seem to offer a solution to this problem.

ZUSAMMENFASSUNG

In diesem Bericht beschreibt der Verfasser eine Reihe von Untersuchungen auf dem Gebiet der Vergasung japanischer Kohlen, die besonders mit Hinsicht auf das Reaktionsvermögen von Koks und Halbkoks im Kaiserlichen Brennstoff-Forschungsinstitut vorgenommen wurden.

An sich sind japanische Kohlen zur Bereitung guten Kokses nicht geeignet, und die heutige Koksindustrie ist zum Teil auf den Bezug chinesischer Kohle angewiesen.

Drei Methoden werden zur Verbesserung des erzeugten Kokses angewendet; erstens durch veränderte Methoden des Heizens der Koksöfen; zweitens durch Erzeugung von Halbkoks bei einer Temperatur von 400 bis 600°C der mit hochflüchtiger Kohle vermischt wird, um Koks von guter Qualität zu geben; drittens durch Studium des Reaktionsvermögens von Koks; dieses Studium wurde im Kaiserlichen Brennstoff-Forschungsinstitut vorgenommen.

Untersuchungen haben gezeigt, dass unterhalb der Abzugsleitung eines Ofens entnommener Koks stets geringes Reaktionsvermögen aufweist.

Die Porösität wird ebenfalls besprochen.

Das Studium des Tieftemperaturvergasungs-Problems in Japan schreitet fort; man hofft, Holzkohle bald durch Halbkoks ersetzen zu können Ebenso wird die Verwendungsmöglichkeit von Schwelteer zum Treiben von Dieselmotoren studiert.

THE MANUFACTURE OF GAS FROM OIL

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS

J. KEWLEY

Paper No. H12

CONTENTS

Of the three types of fuel, solid, liquid, and gaseous, the last undoubtedly offers the advantages of regularity of firing and ease of control. To these may be added, in certain circumstances, facility of distribution. Apart from the widespread use of coal gas in this and other countries, and the use of natural gas for industrial and domestic purposes in the United States and other petroleum-producing countries, considerable quantities of gas made from oil are manufactured in and distributed from central gas works in localities where oil is a cheaper basic material than coal. The gases available differ considerably in calorific value, the natural petroleum gases and those made by the "cracking" of oils being the best in this respect.

It might seem that the manufacture of gas from an oil fuel which itself can be burnt under conditions of high efficiency would not be an economical process, and in practice, when the combustion of liquid fuel fulfils all the requirements, there is nothing to be gained by the previous gasification of the oil. Often, however, the advantages to be gained by using a gaseous fuel, such as ease of control, purity of products of combustion, uniformity of heat distribution and easy control of

temperature, quite outweigh the comparatively small loss of efficiency which cannot be entirely avoided. That this is the case is indicated by the fact that the manufacture of oil gas has developed even in coal-rich countries, partly as an accessory to coal gas manufacture for enriching purposes, and partly for local use. The manufacture of coal gas has limitations, in that the plant is cumbersome and not adapted for small units, being therefore generally confined to central gas works. The manufacture of oil gas can be easily carried out in small units placed where the gas is required, which can sometimes be automatically operated. The many possibilities thus open to the use of oil gas have directed a good deal of attention to this subject and brought about developments in several directions.

As the economies of oil gas manufacture depend so much on the relative values of the basic fuels, oil and coal, available, and on the operating conditions to which definite economic values cannot be given, this aspect of the subject cannot be dealt with in a general paper. The following remarks will therefore be confined to a short comparative description of the extent to which the subject has developed and of a few typical processes.

The subject may conveniently be considered under three heads:

(*a*) The manufacture of oil gas for enriching gases of lower calorific value, *e.g.*, coal gas, producer gas and similar gases.

(*b*) The manufacture of oil gas in place of coal gas in large central gas works in countries where oil is more readily available than coal; and

(*c*) The manufacture of oil gas in small plants which produce the gas where it is required, the special advantages obtained being of such value that they overrule the adverse factor of greater cost of basic material.

Further, the subject may be considered from another point of view, *viz.*, the chemical.

1. The making of gas from oil by a purely cracking process, the constituents of the gas consisting of hydrocarbons and hydrogen entirely.
2. The making of gas from oil by utilising the heat evolved by burning a part of the gas to supply that necessary for cracking the rest, the gas consisting of hydrocarbons, carbon monoxide, hydrogen, and nitrogen.

3. The making of gas from highly heated oil interacting with superheated steam, the gas consisting of hydrocarbons, carbon monoxide and hydrogen, but no nitrogen.

4. Processes involving both (2) and (3).

In order to effect the conversion (1) external heat must be supplied by means of some form or other of retort. This applies also to (3) the reaction in this case being endothermic. In (2) the reaction is exothermic, so that no external heat is required. All of these methods are in use, the most efficient method commercially in any particular instance depending on the particular problem, and local conditions.

The Manufacture of Oil Gas for Gas Enriching

Before the advent of the incandescent gas mantle, coal gas was sold on a candle-power basis. As the gas made from certain coals often failed to reach the necessary standard, enriching by oil gas came into use. Coal gas supplies are, moreover, often supplemented by water gas enriched by oil gas and, occasionally, such carburetted gas alone is used. The plant for making carburetted water gas is simple in comparison with that required for coal gas and it is therefore useful in conjunction with coal gas plants for coping with peak loads or sudden demands.

For this process a petroleum distillate intermediate in character between kerosene and light spindle oil is used, such a distillate being generally termed "gas oil." Distillates having 50 per cent. or more distilling up to 300°C. are generally used, and preference is usually given to oils from paraffinous crudes.

The plant generally used consists of three main parts (Lowe plant)—a generator, a carburettor and a superheater. The generator is merely a water gas producer. The others are cylindrical, upright, steel vessels, lined with firebrick and fitted with chequer brickwork or baffles. They are connected in series. In operating the process, coke placed in the generator vessel is heated by an air blast, the producer gas so formed being allowed to burn with a supplementary air supply in the superheaters, until the necessary temperature is obtained. The air is then cut off and steam blown through the generator in the usual way to make water gas. The gas so produced on entering the carburettor is met

by a spray of the enriching oil, which is there vaporised and cracked, the process being completed in the superheater.

When the temperature has fallen, the oil is cut off and then the steam; the plant is reheated by air injections, thus working intermittently. Any carbon formed by the decomposition or cracking of the oil is burnt off in the blowing stage. Various types of plant operating on the same principle are in use. The temperatures must be carefully controlled, and depend on various factors, such as the quantity of oil and period of injection. The oil should not be injected during the latter part of the gas-making period. Temperatures of about 1,350 to 1,400°F. (730 to 760°C.) may be held in the carburettor, and, roughly, 30°C. higher in the superheater.

The yield of gas obtained is generally from 70 to 90 cu. ft. per imperial gallon (44 to 56 litres per litre) of oil. The calorific value of the gas so obtained cannot be definitely given, as it may vary between the extremes of a purely cracked gas and a pure water gas, according to conditions and the stage of the process.

The Manufacture of Oil Gas in place of Coal Gas

The manufacture of oil gas from petroleum oils in large central gas works in place of coal gas has been developed, particularly in California during the last two decades.

The process used is that of direct cracking of the oil by injection into highly heated chambers. The plant used consists of two large cylindrical steel shells lined with firebrick, connected in series at the lower ends by means of a steel throat piece which is also lined with firebrick. The second chamber is usually larger than the first. Inside both vessels layers of chequer brick and open chambers are arranged alternately. Injector nozzles and burners enter the open chamber through the lining of the vessel. Six inlets are placed at the top of the primary shell and at the bottom of the secondary shell. At the top of the secondary shell is a connection which may be opened into either the gas main or the chimney, as required. The plant is also equipped with a gas water scrubber or washer, no other form of purifier being required. The plant is operated intermittently, the "blowing" and "making" stages alternating. After a "make" run, the operator closes the gas main valve and simultaneously opens the stack valve. He then turns on an air blast, which burns off the carbon left from the previous "making,"

and introduces sufficient oil to heat up the generators to about 1,600°F. (890°C.). When this is effected, he closes the air blast, opens the gas main and closes the stack valve. Oil is next injected by steam into the chambers where it is cracked, giving gas, and at the same time, some coke. This operation being endothermic, reduces the temperature of the chamber until it becomes necessary to raise it again by means of the air-blowing operation. The complete cycle takes from ten to twenty minutes. The gas produced being relatively free from the impurities associated with coal gas, generally requires only a simple scrubbing to remove any hydrogen sulphide and, perhaps, filtering to remove small quantities of finely divided carbon.

Units having a capacity of 2,000,000 cu. ft. per day are generally used, but larger units can be constructed. Oils of various types may be employed, either distillates, the so-called gas oils, or residual fuels.

For a large-size plant the quantity of oil required to make 1,000 cu. ft. of gas is about 6.8 American gallons (5.65 Imperial gallons) or 1 litre of oil to 1.13 cu. m. of gas. Of this oil, roughly 12 per cent. is used for heating the retorts during the blow period, the balance being used for cracking to gas. A quantity of residual tar and lamp black is also produced. The gas so made is not a purely cracked gas as the introduction of steam brings about interaction with the oil with the formation of carbon monoxide. As typical analyses the following may be given :—

	I.	II. Per cent.	III.
Carbon dioxide	2.5	3.7	5.0
Hydrocarbons	2.5	3.8	4.9
Oxygen	0.5	0.4	0.2
Carbon monoxide	15.5	13.4	11.4
Hydrogen	54.2	49.1	44.0
Methane	22.2	27.2	32.2
Nitrogen	2.6	2.4	2.3
Density (air=1)	.404	.435	.468

The calorific value of such gas is from 500 to 600 B.Th.U. per cu. ft.

This process differs from the enriching process first described in that the gas is produced from oil, partly by direct cracking and partly by interaction with highly superheated steam.

In the Ricker-Wolter process, in use on the Continent, fuel oil is used in conjunction with coke, the cracking of the oil taking place on a bed of incandescent coke. It is claimed that the use of heavy oils for gas production gives no trouble in the working of this plant, as the coke left is sufficient to generate the heat in the subsequent blow process. Two generators working in series are used. These are constructed on the lines of an ordinary gas producer. Either generator can be connected, as desired, to the hydraulic seal or to the stack. The primary air inlet is beneath the grate and the secondary air inlet at the top. The blow run commences with the right-hand generator, the blow gases passing through the left-hand generator also. Secondary air is introduced, at the top of the left-hand generator, this causing combustion of the carbon monoxide, which brings the temperature of the left-hand generator up. Blue water gas is produced in the first generator; in the second a combined action of the heated water gas and the incandescent coke on the liquid fuel takes place, the action being completed during the passage through the fuel bed. The generators are usually operated alternately.

The calorific value of the gas is roughly 415 B.Th.U. per cu. ft., and the analysis as follows:—

Carbon dioxide ...	6.6	per cent.
Hydrocarbons ...	2.4	,,
Oxygen	0.6	,,
Carbon monoxide ...	25.1	,,
Methane	10.7	,,
Hydrogen	45.5	,,
Nitrogen	9.1	,,

MANUFACTURE OF OIL GAS IN SMALL-SCALE PLANTS

Apart from the well-established large-scale oil gas manufacture, several methods have been designed and put into practice for the manufacture of oil gas in plants of small capacity. Such plants may prove of very great use in works which may not have convenient cheap supplies of coal gas or which may find the employment of individual unit oil gas plants more economical. Several such processes and plants are well established; others are in course of development. These plants operate either by direct cracking of oil in retorts (*e.g.,* Mansfield and Pintsch processes) by cracking in presence of limited supplies of air to supply the

necessary heat, employing partial combustion (*e.g.*, Hakol-Zwicky, Dayton, and Goldsbrough processes) or by cracking with highly superheated steam.

Manufacture of Gas by Simple Cracking

Oil gas was made in England as early as 1815 by passing oils through highly heated pipes and in 1876 was used for lighting on the Metropolitan Railway. It is now largely used for buoys, lighthouses, and so forth, as well as for laboratories and for general purposes where coal gas is not available.

Pintsch Process

A well-known process in general use for the production of gas for railway carriage illumination is that of Pintsch. The plant consists of two D-shaped horizontal cast-iron retorts about 6 ft. long and 10 in. wide, set with the flat sides downwards, one above the other. The retorts are connected at one end by a bend. The oil is fed into the upper retort on to a tray, where it is vaporised and cracked. The vapours pass into the lower retort, which is maintained at a higher temperature. The gas, after passing through a tar separator, passes through a water washer to remove any hydrogen sulphide, and then, if necessary, through a sawdust filter.

The yield and character of the gas depend on various factors, particularly on the temperature employed. Too high a temperature will produce a gas of high hydrogen content, and consequently a greater deposition of tar. The temperatures generally employed vary from about 775°C. to 900°C. or perhaps higher. The chemical nature of the oil also influences the yield and nature of the gas. It is generally supposed that oils from paraffinous crude oils give the best yields and that those from crude oils rich in cyclic compounds the lowest, but there is reason to doubt this supposition. It is, in fact, a subject on which definite research work might well be carried out. The gas is often compressed into cylinders for use, when it yields a light condensate which can be used as motor fuel. The yield of gas varies considerably, but may be taken as approximately 74 to 80 cu. ft. per gallon of oil used, or about 13 gallons of oil per 1,000 cu. ft. of gas. The yield of tar is about 0.23 gallon and of light oil on compression .06 gallon per gallon of oil used.

A certain amount of carbon is also deposited in the retorts. The gas possesses a high calorific value (about 1,300 B.Th.U. per cu. ft.), and is composed entirely of hydrocarbons and hydrogen, as no air or steam is used in its manufacture.

Unsaturated hydrocarbons ...	36	per cent.
Saturated hydrocarbons ...	50	„
Hydrogen	12	„
Acetylene, etc.	2	„
	100	„

Mansfield Process

Another well-known process is that of Mansfield. The apparatus employed is a vertical cylindrical cast-iron retort, which can be heated in a furnace fired by any suitable means. The goose-neck offtake pipe from the retort is connected by means of a lead seal and leads the gas through the hydraulic main direct into the gas holder. The oil is introduced by a central tube, which allows it to drop on to the red-hot bottom of the retort, where instantaneous cracking takes place. The largest type of retort made can produce about 250 cu. ft. of gas per hour. The process, like that of Pintsch, is intermittent, as the accumulation of coke in the retort eventually necessitates a shut down for clearing, the process being meanwhile carried out in another retort. The working temperature is a bright cherry red, approximately 870°C. If the temperature is too low cracking is incomplete and vaporised material is carried away, resulting in an increased separation of tar from gas. If the temperature is too high, excessive quantities of coke and tar are produced; in either case the yield and quality of the gas is affected. The process is applicable to any oils, creosote, palm oil, castor oil, coconut oil having been successfully used. Petroleum gas oil is, however, generally used.

The plant is simple to operate and convenient for laboratory purposes, as the units are small. Increased capacity is obtained by multiplication of units.

The yield of gas from ordinary petroleum distillates, such as gas oils, is approximately 90 cu. ft. of gas per Imperial gallon of oil used, or 11 gallons of oil per 1,000 cu. ft. of gas. In addition to this, about 220 lb. of coal for heating are necessary for every 1,000 cu. ft. of gas. Coke is produced in the retort, the quantity formed varying considerably with the quality of the oil and, of

course, with the temperature conditions; it generally ranges from 1.5 oz. to 4 oz. per Imperial gallon of oil cracked. The composition of the gas varies with the nature of the oil and the conditions of operating. It is of high calorific value—nearly three times that of coal gas (roughly 1,400 B.Th.U. per cu. ft.), and consists entirely of hydrocarbons and hydrogen, carbon monoxide being naturally absent. A typical analysis is as follows :—

Methane and ethane	49 per cent.
Ethylene, acetylene, etc. ...	45 „
Hydrogen	4 „
Carbon dioxide and nitrogen ...	1 „

Manufacture of Oil Gas by Processes involving Partial Combustion.

Plants of the types described above suffer from the disadvantage of intermittent working and the relatively low efficiency consequent on the method of carrying out the operation in externally heated retorts. The deposition of coke, which is unavoidable with a purely cracking process, renders a continuous plant impracticable. A continuous method must, therefore, be looked for in another direction. Plants of the Hakol or Dayton type afford examples of the way in which continuity of operation has been attained, but these plants do not produce gases of such high calorific value as do the Mansfield and Pintsch types. The Hakol and Dayton plants work on the producer gas principle, yielding gases containing much nitrogen and, therefore, of relatively low calorific value.

Hakol-Zwicky Process

The Hakol-Zwicky process operates on the principle of effecting cracking by the heat supplied by partial combustion of the oil. This partial combustion is carried out under definite pre-determined and constant conditions, so that the oil is converted into a combustible and permanent gas without appreciable formation of coke or other by-products. One of the difficulties in oil gasification has always been the deposition of carbon during the cracking process. This deposition, apart from the loss of combustible material, is objectionable on account of the interference with the operation brought about by the necessity for cleaning the retort. In the case of the Hakol-Zwicky process the conditions and

relative supplies of air and oil are so controlled that no carbon is deposited in the retort; the process can thus be worked continuously. The apparatus occupies a very small space for its output. The retort or conversion chamber is cylindrical in form and lined with refractory material; it is set horizontally and fitted with a gas outlet on the top, a door at the back and a fuel injection arrangement in front. The oil to be gasified is, after filtration, passed through a heating coil and heated to 160 to 190°F., according to the class of oil used. It is then fed through a special control mechanism to the injector. The needle valve of this injector is connected with the air inlet control, so that any predetermined ratio of oil to air can be maintained independent of variations in rate of air supply. The output of the plant can thus be reduced to 25 per cent. of the maximum, without impairing the efficiency or upsetting the operation of the plant. The air can be supplied by a small fan, as pressures of only a few inches of water are necessary. The generator or convertor, *i.e.*, the retort, is so constructed that the jet of oil impinges on a cushion of secondary air introduced at the back of the retort in such a way that the flame is turned back along the chamber walls without actually touching them. In this way the deposition of carbon is avoided. The partial combustion of the oil thus supplies the heat necessary to crack and gasify the remainder. The operation of the plant is simple. It is started by means of a small wood fire in the chamber, which is blown by air, and which ignites the fuel in the course of a few minutes.

The resulting gas is composed of hydrogen, methane, carbon monoxide, unsaturated hydrocarbons, nitrogen, and carbon dioxide, the following being a typical analysis :—

Carbon monoxide	17 per cent.
Hydrogen	9.3 ,,
Methane	5 ,,
Unsaturated hydrocarbons ...	2.7 ,,
Carbon dioxide	3.8 ,,
Nitrogen	62.2 ,,

The issuing gas contains small quantities of impurities, such as finely divided carbon and a little tar in the form of tar fog. If it is to be used directly for heating purposes, these impurities need not be eliminated, but if the gas is required for use in internal combustion engines, or for distribution, they

must be removed. (This is effected by filtration through glass wool, or some similar means.) When the gas is used for direct firing, about 98 per cent. of the heat value of the original oil is available in the form of hot gas; if the gas be cooled for distribution, the process is about 80 per cent. efficient. The calorific value of the gas varies from 150 to 200 B.Th.U. per cu. ft. 1,000 cu. ft. of this gas are produced from 1.26 Imperial gallons of thin fuel oil.

DAYTON PROCESS

The Dayton plant operates on a similar principle. Air and oil are fed into hot retorts through an atomiser arranged to deliver the oil and air in the correct proportions. Within the retorts partial combustion of the oil takes place, liberating sufficient heat to promote and continuously maintain the temperature necessary for thermal decomposition of the rest of the fuel. The air can be adjusted to do this without oxidising the products further. Roughly, 9 per cent. of the available heat in the oil is obtained in the form of tar, and about 80 per cent. in the form of gas. The apparatus works continuously, the partial combustion of the oil supplying sufficient heat to maintain the reaction temperature and make up the heat lost through radiation and conduction of sensible heat carried out by the hot gases. The requisite proportion of oil and air having once been determined, it must be maintained constant for that particular type of oil. The complete installation is small and compact, only 1,500 sq. ft. of floor space being required for a plant capable of producing 1,000,000 cu. ft. per day, and one man per shift is sufficient to operate it.

The gas, after leaving the retort, passes through a pre-heater in order to heat incoming air. It then passes through a scrubber where the light tars are precipitated, and finally through a secondary tar extraction system, which removes the heavier tars, leaving the gas free from tar and sulphur compounds.

The quality of the gas can be varied at will, from 300 to 500 B.Th.U. per cu. ft., by adjusting the air-oil vaporising control on the atomiser. Gas, having a higher calorific value than 550 B.Th.U. per cu. ft., cannot be obtained with this plant. Any sulphur in the oil appears in the gas as sulphur dioxide, which can readily be removed by scrubbing.

About four gallons of fuel oil are required for the production of

1,000 cu. ft. of gas of 450 B.Th.U. per cu. ft. As 0.28 gallons of tar are produced, the oil consumption practically amounts to 3.72 gallons per 1,000 cu. ft.

A typical analysis of the gas produced is as follows:—

Carbon dioxide	6.1 per cent.
Unsaturated hydrocarbons ...	14.7 „
Saturated hydrocarbons ...	7.8 „
Oxygen	0.9 „
Carbon monoxide	5.6 „
Hydrogen	1.7 „
Nitrogen	63.2 „

Goldsbrough Process

A process similar in principle to the two last described has recently been devised by Goldsbrough, and is now in course of development. The heated oil fuel is also injected into a retort or generator with a supply of air insufficient for complete combustion but sufficient to supply heat for the cracking of the unburnt part of the oil. The retort, which is of peculiar construction, is lined internally with a catalyst which, it is claimed, prevents deposition of carbon. The retort consists of two frustrum-shaped vessels placed within each other. The outer surface of the inner cone is provided with a continuous spiral fin which fits against the under surface of the outer cone, thus forming a spiral passage. This is enlarged at the entrance to a chamber into which the oil is sprayed by the air jet.

The apparatus is able to produce a gas of relatively high calorific value, *viz.*, 600 B.Th.U. per cu. ft. or even over, without formation of carbon in the apparatus. The gas is clean, and deposits only small quantities of oil and very small quantities of lamp black. As the supplies of oil and air are suitably adjusted and arranged so as to vary with each other and maintain the set proportions, the plant can operate continuously. The gas produced in this manner is of the producer type. A sample of it gave on analysis:—

Saturated hydrocarbons ...	17.9 per cent.
Unsaturated hydrocarbons ...	9.5 „
Carbon monoxide	11.2 „
Hydrogen	7.0 „
Nitrogen	54.4 „

Manufacture of Oil Gas using Superheated Steam.

Goldsbrough has been able to develop his process in another direction, namely, that of producing gas by cracking and interaction of the highly heated gas with highly heated steam. The reaction is endothermic. The gas produced is very different in character from that obtained in the continuous processes described above. Not being diluted with nitrogen, it has a high calorific value; it is also rich in unsaturated hydrocarbons. So far, however, the process has not reached the development stage.

The plants and methods above described yield gases of two main types, the hydrocarbon type made by the direct cracking methods and the air gas or producer gas type, containing large proportions of nitrogen. The compositions of these gases show very large variations in character, being dependent on a number of factors, such as the composition of the oil, the working temperatures and the proportions of air employed.

The selection of the type and process most suitable for a particular operation depends not only on the type of gas required, but also on various economic and other considerations.

ZUSAMMENFASSUNG

Aus Öl erzeugtes Gas gewinnt nicht nur als Bereicherungsmittel für Kohle und Erzeugergas standig an Bedeutung, sondern auch als Brennstoff in Gegenden, in denen billige Kohle nicht zu haben ist oder wo nur geringe Gasmengen benötigt werden. Gas wird fur Bereicherungszwecke im allgemeinen durch Cracken von Gasöl hergestellt. Der Vorgang ist intermittierend; der Generator wird zuerst durch Brennen von Öl oder Erzeugergas geheizt; dann wird das Öl in den zu bereichernden Gasstrom hineingestäubt. Wenn die Temperatur im Generator fallt, wird der Vorgang wiederholt. Die Verwendung von Gasöl anstelle von Kohlengas ist besonders in Kalifornien weit verbreitet. Es wird dort ein intermittierendes Verfahren mit unmittelbarem Cracken des Öles benutzt. Zur Herstellung von Gas in kleinen Anlagen gibt es verschiedene Verfahren. Bei den Verfahren von Pintsch und Mansfield wird das Öl in geheizten Retorten gecrackt; beide Verfahren sind intermittierend. Die Verfahren von Hakol-Zwicky, Dayton und Goldsbrough hingegen sind kontinuierlich und beruhen darauf, dass die Hitze entsteht beim Verbrennen des einen Teiles des Öls zum Cracken des Restes. Das erzeugte Gas vermischt sich naturlicherweise mit Stickstoff, wodurch sein Heizwert sinkt. In neuester Zeit wurde ein zweites Goldsbrough-Verfahren ausgearbeitet, bei dem überhitzter Dampf zum Cracken des Öles zur Anwendung kommt. Dieses hat den Vorteil, ein Gas von hohem Heizwert zu geben.

SOME TECHNICAL AND ECONOMIC ASPECTS OF THE BY-PRODUCT AMMONIA RECOVERY PROBLEM

THE JOINT FUEL COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS, THE SOCIETY OF CHEMICAL INDUSTRY, THE COKE-OVEN MANAGERS' ASSOCIATION, AND THE INSTITUTE OF FUEL

P. PARRISH

Paper No. H13

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No one denies that the manufacture of ammonium compounds from by-product ammonia on an economic basis constitutes a distinct problem at the present time.

The progressive increase in the production of ammonium sulphate manufactured from synthetic ammonia, and the consequent fall in selling price, makes the problem more acute.

An indication of the gravity of the situation is afforded by the recollection that fifteen years ago the realisation by many gas undertakings by the recovery of ammonia and its conversion to sulphate of ammonia or other ammonium salts, represented 15 to 20 per cent. of the cost of the coal. To-day, the larger gas undertakings deem themselves fortunate if their revenue from by-product ammonia covers 5 per cent. of the cost of the coal.

These conditions, in a measure, apply to coke ovens.

The cost of recovering by-product ammonia to-day at many medium and small gas undertakings ranges from 6d. to 1s. 6d. per ton of coal carbonised.

The question arises at once: Why should it cost more to recover and subsequently release ammonia from gas liquor than

does to produce ammonia by a complicated process, involving expensive plant?

It is not proposed to give a direct answer to this question, but rather to examine one or two technical and economic aspects which must, at least, afford some information relative to the question propounded.

One outstanding factor cannot be ignored. This relates to the magnitude of the manufacturing operations at the synthetic ammonia works at Billingham. It has been announced that they hope to complete their programme by 1930, when the total output of ammonium products will be equivalent to 2,100 tons of sulphate per day, or over 750,000 tons per year. Even assuming this programme is not realised, and that, in view of Lord Melchett's declaration at the Adriatic Conference, that the eventual output will be 1,000 tons per day, or 360,000 tons per year, it is a stupendous quantity. It is known that the largest works in this country producing ammonium sulphate from by-product ammonia does not exceed 25,000 tons per year.

It is recognised that gas for power, lighting and heating is the primary product of gas undertakings, and that the recovery of ammonia is a secondary consideration. Similarly, in the case of coke-oven plants, coke is the primary product, and the recovery of ammonia is a less important consideration.

Ammonia, however, must be recovered, whether gas or coke is the primary product, and, dependent on the nature and efficiency of the recovery process, a revenue may result, or a loss of some significance may be incurred.

Many agree that there are far too many gasworks carbonising coal to-day. It is true that the cost of the transmission of gas is an important item in the selling price of coal gas. Even so, it cannot be doubted that carbonisation could be concentrated at a number of points with advantageous results. Any such concentration would be a step in the right direction in mitigating the gravity of the by-product ammonia recovery problem.

Despite any such centralisation of carbonisation as is foreshadowed, the belief is held that the recovery of ammonia at the majority of works should only proceed to a certain point, and that its final treatment should be carried out at a number of centrally-situated chemical works.

At such works, spent oxide should be converted into sulphuric acid, and the ammoniacal intermediate products should undergo

treatment in the manufacture of final ammonium products. What the situation of these works should be, and how many carbonising undertakings they should embrace, needs to be viewed from both the technical and economic aspects. What is involved will be discussed later.

During the last twelve months, many suggestions have been offered as a partial or complete solution of the problem in question. Some refer to the method by which the ammonia is recovered; others relate to the utilisation of anhydrite in lieu of sulphuric acid in the manufacture of ammonium sulphate.

Some (and among these is Mr. L. H. Sensicle, *vide Gas Journal*, Vol. CLXXXII, pp. 384-391), think that the problem can be solved by adopting the direct process for the recovery of ammonia as ammonium sulphate, on the lines conducted at some of the coke-oven plants to-day. Others think that concentrated gas liquor should be produced and sent to a centrally-situated works for treatment; others think this intermediate product should take the form of concentrated ammonia liquor, and there are some, among whom the writer is one, who think that the ammonia should be recovered at gasworks in the form of ammonium sulphate solution containing 40 per cent. $(NH_4)_2SO_4$, and that this should be sent to centrally-situated works for conversion into ammonium sulphate of uniform quality and special crystal size.

It will be well to review briefly these suggestions, in order that a complete picture of the problem of by-product ammonia recovery can be correctly envisaged.

I—In the writer's view there is no such thing as a direct process of sulphate of ammonia manufacture. It is true that coke-oven recovery plants are said to operate the direct process, but the last-named is more imaginary than real. A salient feature of the so-called direct process is the avoidance of any condensation prior to the absorption of ammonia in sulphuric acid. If one succeeds, ammonium chloride is usually carried to the saturator, and this apparatus and the mains leading from it must suffer from corrosion by hydrochloric acid, due to the decomposition or dissociation of ammonium chloride.

Efforts to overcome corrosion by spraying tar, creosote, or water, to remove ammonium chloride, have not proved too successful. With a spray of the type indicated, a thick, viscous tarry mass containing ammonium chloride is produced. This ha

to be treated in a suitable way, for the recovery of muriate of ammonia, which is impure, and for which there is only a limited sale at a very low price.

It is known that the quantity of devil water condensed after the saturator is not inappreciable, and that it possesses toxic properties. Many determinations with average coal, as carbonised at gasworks, have been made, and it is known that (*a*) about 16 gallons of water per ton of coal carbonised are due to the coal substance itself. In addition to this, the water (*b*) introduced *via* the 70 per cent. sulphuric acid has to be evaporated, and/or entrained, and this amounts to 80 gallons per ton of sulphate of ammonia (25.7 per cent. NH_3), made, or assuming a recovery of 28 lb. of sulphate of ammonia per ton of coal carbonised, one gallon of water per ton of coal treated.

Where 80 per cent. sulphuric acid is used about 47 gallons of water have to be evaporated and/or entrained, representing on the former basis 0.6 gallon per ton of coal carbonised. Further, 15 to 20 gallons of wash water per ton of sulphate of ammonia manufactured have to be introduced to the saturator, to maintain the centrifugal in a satisfactory condition for operation.

If the direct ammonia recovery process were installed at gasworks where steaming is the vogue, the quantity of water may well increase to a very sensible extent, from (say) 20 to 30 gallons or more, per ton of coal carbonised. Moreover, the quantity of tar is not nearly so satisfactory as that yielded by the semi-direct or indirect processes. In some cases it resembles pitch rather than tar.

It would appear that the so-called direct process is unsuitable for application to gasworks, if for no other reasons than those stated above.

II--The semi-direct process is the one favoured by most chemical engineers and coke-oven managers in this country. It aims at reducing the production of gas liquor to a minimum. Its application to gasworks practice would introduce defects which cannot be ignored. Among these, mention may be made of the following:

(*a*) Dilution of the bath by the water vapour resulting from the condensation of steam from the steam-ammonia stream constitutes a disability, which must inevitably occasion loss by reason of the production of redundant mother liquor.

(*b*) The reduced solubility of ammonium sulphate in the saturator liquor, due to the bath being operated at a temperature

of 40 to 46°C., would lead to the use of an intermittent feed of acid, with the result (1) that tarry matter would be arrested in such a form as to constitute a nuisance, and (2) sulphate of ammonia in the form of a fine crystal of an indifferent colour would be produced.

It is true that steps could be taken to reduce or circumvent these difficulties. It is known that Koppers pre-heat the gases leading to the saturator, and that the Semet-Solvay Co. provide a dephlegmator with a view to removing water vapour, so as to avoid diluting the bath. Despite these provisions, which have certainly helped to make the process more satisfactory, it cannot be said that the sulphate of ammonia produced is altogether satisfactory in point of crystal size.

What are the alternatives to the process already briefly discussed? They would appear to be these :—

III (*a*)—Gasworks could still continue to recover ammonia as gas liquor, as obtains to-day, but instead of distilling the ammoniacal liquor for the manufacture of sulphate of ammonia, it would be possible, by a slight modification of the sulphate of ammonia plant, to produce concentrated gas liquor. This product could be sent to a centrally-situated works, at a reasonable cost as regards transport, for conversion to suitable ammonium products, or

IV (*b*)—Steps could be taken to recover the ammonia as a solution of ammonium sulphate, containing 40 per cent. $(NH_4)_2SO_4$.

It will be well to examine what is involved in connection with the two processes in question.

Process (a): Concentrated Gas Liquor

It is certain that at many works it will be profitable to concentrate gas liquor, rather than send it, containing about 2 per cent. of ammonia, to chemical works at some distance, and then be called upon to pay for its removal.

An example can be cited by the author from personal experience, which is undoubtedly typical of many cases at other gasworks.

The works in question carbonise 5,000 tons of coal per year and produce 400 tons of gas liquor of 11 oz. strength.

At present, the gas company is paying 4/- per ton for the removal of the ammoniacal liquor from its works. At a cost of £500 it would be possible to erect plant capable of distilling one ton of gas liquor per hour, and producing concentrated gas liquor of 15 per cent. NH_3 content. The cost of concentrating 400 tons

of gas liquor in a 1 ton per hour ammonia still at such works would be approximately as follows:—

1. Labour $\frac{400 \text{ tons}}{24 \text{ tons per hou}}$ =16 days' wages; three shifts per 24-hour day=48 shifts at 10/6 per shift	£25	4	0
2. Steam for distillation, based on 30 lb. per 100 lb. of gas liquor=120 tons at 3/- per ton	18	0	0
3. Cooling water and repairs and maintenance	5	0	0
4. Interest on capital and depreciation on plant, at (say) 10 per cent. per annum on £500	50	0	0
	£98	4	0

For such concentrated gas liquor it would be possible to pay, based on present market prices for sulphate of ammonia, for agricultural purposes, 7/- per ton, delivered into tank wagons f.o.r. at the gasworks.

Thus, the realisation for concentrated gas liquor would be:—

(*a*) 400 tons of gas liquor at 11 oz. strength would yield $\frac{400 \times 11 \text{ oz.}}{69 \text{ oz}}$ = (say) 63¾ tons of concentrated gas liquor (15 per cent. NH_3 content) at 7/- per ton	£22	6	3
(*b*) In addition to the above realisation, the gas undertaking would not have to bear the debit of 4/- per ton on gas liquor of 11 oz. strength. Therefore, 400 tons at 4/- per ton	80	0	0
	£102	6	3
Thus, the economy effected by the installation of plant for the production of concentrated gas liquor would be	£4	2	3

N.B.—*The above example does not contemplate the utilisation of the fixed ammonia; it only provides for the free ammonia.*

Although this saving is small, it is certain that it is in the right direction. The above example concerns a gasworks about twenty-five miles from the chemical works which treats the gas liquor.

Of course, the greater the distance of a gasworks from the ammonia works, the more profitable is the concentration of gas liquor likely to prove.

So far as medium-sized works are concerned, what is necessary in their case is the installation of a reasonably large unit of

distillation plant. Labour constitutes an important item in the cost of concentrated gas liquor.

Similarly, steam, lime, and depreciation represent important items.

Generally speaking, each works must decide for itself whether the manufacture of ammonium sulphate or the production of concentrated gas liquor, or the sale of gas liquor as such, or the production of ammonium sulphate solution, is the better proposition.

Process (b): Ammonium sulphate solution.

It is known that there is no technical difficulty in the recovery of 45 per cent. of the total ammonia produced in the straight carbonisation of coal, as ammonium sulphate solution containing 40 per cent. $(NH_4)_2SO_4$. Indeed, the whole of the ammonia can be so recovered, provided the virgin gas liquor is distilled and suitably arrested in sulphuric acid.

Where a gasworks is situated in close proximity to the sulphuric acid works, having ammonium sulphate plant, there can be no doubt that this process is likely to prove attractive, as the recovery of ammonia resulting from the carbonisation of coal as ammonium sulphate solution, 40 per cent. $(NH_4)_2SO_4$ content, need be no more expensive than the production of gas liquor. That it is a much more valuable product goes without saying.

It is true that in any such process extra work is thrown on the oxide of iron purifiers, which may be called upon to remove an additional 10 per cent. of hydrogen sulphide. This need not, however, constitute any serious disadvantage. What is somewhat more serious is that the carbon dioxide content of the gas is likely to be increased by 0.5 per cent., and this will affect the flame temperature to such a degree as to warrant the consideration of means for eliminating the CO_2 content of the gas by an alkaline solution after the sulphuric acid special absorber.

The plant for the treatment of ammonium sulphate solution, 40 per cent. $(NH_4)_2SO_4$ content, in the production of crystalline ammonium sulphate, is simple to operate, and not unduly expensive as regards capital cost.

Moreover, a very attractive product can be produced from the view-point of crystal size and character, as well as from the aspects of colour and neutrality.

Where the gasworks is situated some distance, say, more than 25 miles, from a chemical works, then the cost of the carriage on

sulphuric acid (namely, about one ton per ton of ammonium sulphate), and the removal of 2½ tons of ammonium sulphate solution (40 per cent. $(NH_4)_2SO_4$ content) per ton of sulphate, renders this method of operation less attractive than process (*a*), to which attention has already been directed.

Other methods are available for the utilisation of gas liquor, but it is impossible to deal with these in the limited time available.

V—*Process* (*c*) : *Anhydrite in lieu of sulphuric acid.*

What is important is that an examination should be made of the process for the manufacture of ammonium sulphate, where anhydrite is used in lieu of sulphuric acid, in more detail than has hitherto been extended to this aspect of the subject.

Statements have appeared from time to time to the effect that the by-product ammonia problem may possibly be solved by resorting to the use of anhydrite in lieu of sulphuric acid, in the manufacture of sulphate of ammonia.

Such statements should not be accepted implicitly. Indeed, the whole position should be examined scrupulously.

The number of unit processes involved in the utilisation of anhydrite in the manufacture of ammonium sulphate is not generally realised. Neither is the importance of large-scale operations, nor the economics of the process, fully appreciated.

In an article under the title "Synthesis of Ammonia from Coke-Oven Gas," by T. Biddulph-Smith, which appeared in the *Iron and Coal Trades Review*, page 222, February 17, 1928, the following reference was made to the gypsum (*sic*) process :—

> "The ammonia is dissolved in water, and carbon dioxide is passed through the solution, combining with it to form ammonium carbonate. To this solution of ammonium carbonate is then added a quantity of finely-powdered gypsum, and the mixture is agitated for a specified time, the temperature being maintained below 20°C, when a reaction takes place in which the acid radicals are exchanged, ammonium carbonate and calcium sulphate giving ammonium sulphate and calcium carbonate.
>
> The ammonium sulphate, being soluble in water, is in solution, whilst the calcium carbonate, which is insoluble, is in suspension; hence, after being allowed to settle, the latter can be sludged off. The clear solution of ammonium sulphate is then evaporated down and allowed to crystallise, the crystals being ultimately dried. As there is no free acid, neutralising is unnecessary, and it is by controlling the rate of crystallisation that the size of crystals can be regulated. The absence of free acid also obviates the necessity for expensive leadwork.
>
> The carbonate of calcium which has been filtered off is sold for the

manufacture of cement and as a dressing for the land; or if calcined, it would form a much cheaper and purer lime for use in iron and steel manufacture, especially if mixed with flue dust in sintering plants. One ton of gypsum contains 10.25 cwt. of sulphate radical (SO_4) and one ton of anhydrous calcium sulphate—which is found on the surface of the gypsum strata—contains 14.10 cwt.; whereas 1 ton of 80 per cent. sulphuric acid contains only 15.66 cwt., so that if we take the cost of gypsum at 12/- and sulphuric acid at 58/6 per ton, the cost of sulphate radical per cwt. would be 1/2½ and 3/9 respectively."

Further, in the cost sheet concerning the gypsum (*sic*) process, the following relevant figures were given :—

		£	s.	d.
Debit.	82 tons of gypsum at 12/6 per ton ...	51	5	0
Credit.	51 tons of ammonium sulphate at £8 15 0 per ton	507	10	0
	70 tons of calcium carbonate ...	—		

In order to obviate any misconception concerning the anhydrite process, it is important to examine three pertinent questions :—

1. In what form must by-product ammonia be recovered to admit of the application of the anhydrite process?

2. What are the unit processes involved in the production of ammonium sulphate from anhydrite? and

3. How does the cost of anhydrite, taking the extra unit processes involved into consideration, compare with the price of sulphuric acid?

1. By-product ammonia would need to be recovered as gas liquor, and by a simple distillation could be converted to concentrated gas liquor—a form in which it would be suitable to admit of the application of the anhydrite process.

Concentrated gas liquor contains about 15 per cent. of ammonia (it should not contain more, otherwise difficulty may arise through solidification), usually as carbonates and sulphides of ammonium.

2. The unit processes are as follow : (*a*) recovery of by-product ammonia as gas liquor; (*b*) distillation of gas liquor in the production of concentrated gas liquor; (*c*) recovery and purification of flue gases as a source of CO_2; (*d*) carbonatation of the ammonium sulphides of the concentrated gas liquor; (*e*) recovery of the H_2S released in the carbonatation process; (*f*) grinding and screening of anhydrite to a suitable size; (*g*) interaction of ammonium carbonate with calcium sulphate in a series of suitable vessels; (*h*) filtration of ammonium sulphate-calcium carbonate magma; (*i*) evaporation of ammonium sulphate solution and its

subsequent crystallisation, centrifuging and drying; and (*j*) removal and treatment of calcium carbonate sludge.

It will be well to supplement the foregoing information by one or two brief notes concerning the technique of the anhydrite process.

Calcium sulphate is found in this country in three forms, (*a*) as gypsum, $CaSO_4 2H_2O$; (*b*) as hemi-hydrate, $2CaSO_4 H_2O$; and (*c*) as anhydrite, a typical analysis of which is given below :—

$CaSO_4$	89.9 per cent.
Uncombined water ...	9.8 „
SiO_2	0.15 „

Anhydrite is frequently supplied in large pieces, sometimes weighing 1½ cwt. each. It must, therefore, be ground.

The grinding plant required is of a special type. It must embrace first a ring roll or toggle breaker, which will reduce the 1½-cwt. lumps to about 6-in. cube. Secondly, the 6-in. cube material must be fed to a rotary type of crusher, where the size is reduced to about 1-in. cube. Thirdly, the 1-in. material must be fed to a ring roll machine, or similar plant, where the anhydrite can be crushed almost to an impalpable powder.

It will be realised from the foregoing that there are three stages in the grinding operation. In connection with the ring roll machine, a mechanical air separator will be required, as well as an elevator, dust collecting device and transmission.

The roll jaw crusher for a plant capable of producing 3 tons per hour of anhydrite, reduced to such a size that not more than 2 per cent. of tailings remain on a 100×100 mesh screen, will involve an estimated capital expenditure of £3,500, of which £600 is for a building for housing the plant.

Basing on 10 per cent. for depreciation and 5 per cent. for interest on capital, the cost of screening will be 4s. per ton—a charge which cannot be ignored.

It should not be overlooked that the speed of reaction between ammonium carbonate and calcium sulphate is influenced by the particle size of the anhydrite. Working on a semi-technical scale, and basing on a time contact of 15 minutes, it is known that the rate of conversion of a solution of quarter normal ammonium carbonate $(NH_4)_2CO_3$ at (*a*) 30°C. and (*b*) 45°C., to ammonium sulphate, varies with the particle size of the anhydrite as is revealed by the following figures :—

	(a) per cent.	(b) per cent.
All through 120 mesh screen ...	92.0	91.0
Between 80 and 120 mesh screen ...	87.7	84.5
„ 60 „ 80 „ ...	49.7	—
„ 40 „ 60 „ ...	49.7	—
„ 30 „ 40 „ ...	49.2	—
„ 20 „ 30 „ ...	48.0	—
Under the above conditions, but with a time contact of only 5 minutes all through 120 mesh screen ...	85.6	—

The reaction between anhydrite, concentrated gas liquor, and flue gases containing carbon dioxide, is effected in a special reaction vessel provided with a stirrer and cooling coils. The vessel should also be jacketed, to aid cooling. The anhydrite should be introduced to the vessel, and the concentrated gas liquor and some wash water from a previous operation should be added.

Flue gases containing carbon dioxide can now be introduced, and their passage continued until the whole of the sulphides in the concentrated gas liquor are decomposed.

As ammonia and hydrogen sulphide will escape the first reaction vessel during the time that the flue gases are introduced, it is necessary to provide a number of these vessels. Six represents a satisfactory complement, and these should be so arranged that they can be operated either by forward or backward rotation, thus admitting of any vessel being put out of action to allow ot its discharge and recharging.

Under certain conditions of operation it has been found that a 20 per cent. ammonium sulphate solution is the highest concentration to which one can work satisfactorily without interference from precipitated calcium carbonate.

In this connection it may be advisable to leave 2 or 3 per cent. of unconverted calcium sulphate with the calcium carbonate, rather than involve a second or third filtration. One of the advantages of the use of concentrated gas liquor is that about 80 per cent. of the ammonia exists as carbonates of ammonia. But flue gases containing CO_2 must be used to convert the remaining 20 per cent. of the ammonia, existing usually in the form of sulphides, to carbonates.

How the flue gases should be treated so as to be rendered suitable for application to the process is a matter that needs careful

consideration. Flue gases are usually available, but if these result from the combustion of coke, they may contain from 40 to 100 grains of SO_2 per 100 cu. ft., in addition to which there will be entrained dust and grit.

The question arises at once : can flue gases be used direct or must they be purified? Flue gases may have a varying temperature of from 200 to 600°C., according to their origin. If the CO_2 in the flue gases is to be of service for a carbonatation process such as that contemplated, it will be necessary to introduce them to the plant at a temperature not exceding 20°C.

From a knowledge of the use of the carbon dioxide content of flue gases for other purposes, the necessity for cooling becomes evident. If the flue gases were merely passed through condensers to attain the necessary reduction of temperature, difficulty would arise through corrosion, due to the formation of a weak solution of sulphurous and sulphuric acids.

The best method to adopt is to pass the flue gases through a packed tower, down which sufficient water is run to cool the gases to 20°C. Operating in this way, the SO_2 would be almost wholly absorbed, and the grit and dust would be arrested.

From the point of view of suitable plant it should be emphasised that if corrosion is to be avoided the flue gases must be fed to the packed tower at a temperature preferably above dew-point (which may be of the order of 150 to 180°C.); that the tower must be lined with acid and heat-resisting tiles, packed with acid and heat-resisting rings, and generally constructed of such materials as will be found to resist the attack of weak solutions of sulphurous and sulphuric acids. The pipes and suction fan after the packed tower could be of cast iron.

The agglomeration of large nodules and crusts of precipitated calcium carbonate it a frequent cause of unsatisfactory filtration. Where vessels of a certain minimum capacity are employed, this difficulty can be minimised. At some works it has been so acute as to lead to alternative methods of treatment being suggested. One such method is that devised by the firm of Otto & Co., where a special reaction column is used, the vertical axis of which consists of a mechanical rotating shaft carrying at equi-distant intervals cone-shaped collars, projecting in a downward direction.

The separation of the ammonium sulphate from the calcium carbonate calls for special comment. Some qualities of anhydrite

contain argillaceous matter, and the separation of the colloidal suspension of calcium carbonate from ammonium sulphate solution produced in the reaction has constituted a very difficult problem.

All the usual types of filtering plant have proved unsatisfactory, by reason of the large amount of wash water required to free the precipitate from the bulk of its ammonium sulphate. The solutions obtained are so dilute that the cost of evaporation is prohibitive.

The adoption of suction filters completely immersed in the liquors has been responsible for the solution of the difficulty. These filters are immersed in the reaction mass, and a vacuum is applied to their interior. The precipitate deposits in a uniform layer on the outside of the filters, and the clear filtrate passes through.

A simple form of this type of filter consists of a wooden frame, two sides of which are provided with filter cloth, the wooden sides themselves being perforated. One or more tubes crossing the frame on its narrow side are used for applying the suction on the inside of the filter.

When the deposit of calcium carbonate is thick enough, the whole filter is immersed in fresh water, either by removing it from the reaction vessel or by discharging the latter and then refilling with water. The washing of the uniform deposit in the filter can be effected easily, and the amount of water used is comparatively small.

After washing, the cake of calcium carbonate is readily detached from the filter, either by blowing compressed air through the filter from the inside, or by flushing from the inside with water under pressure.

The principle underlying this method of filtration is not new, but is only applicable to precipitates depositing in a coherent layer, at the same time being such as to be cellular in structure and readily permeable by water without channelling and without becoming detached.

Where the anhydrite contains undue quantities of argillaceous impurities, it is usually preferable to submit the material to a preliminary calcination at 300°C., in rotary furnaces of the cement type. This, of course, introduces another source of expense, which must be taken into consideration when contrasting the price of anhydrite with that of sulphuric acid.

The evaporation of the resulting ammonium sulphate solution

has not altogether been immune from problems. At first sight it may be imagined that it would not be difficult to secure a neutral or alkaline solution of ammonium sulphate. This is perfectly true. But an alkaline solution of ammonium sulphate is not without corrosive properties, and may prove to be, under certain conditions, as troublesome as an acid solution of sulphate of ammonia, particularly if the final colour of the ammonium sulphate is regarded as one of importance.

It is known that trials have been made with many materials, such as cast iron, Staybrite, and stainless steel, etc. No one who has had any experience of the use of these materials can reach any other conclusion than that there is much merit in an homogeneously lead-lined steel evaporator.

Enough has been said to make it clear that the utilisation of anhydrite in lieu of sulphuric acid for the manufacture of ammonium sulphate is not nearly so simple a process as many are inclined to suppose. Many unit processes are involved; additional chemical supervision is necessary, and the efficiency of the conversion of the calcium sulphate content of the anhydrite to ammonium sulphate, the efficiency of the use of the CO_2 content of flue gases and of ammonia in the interaction, must be carefully considered.

It is known that both ammonia and calcium sulphate are lost in the calcium carbonate cake, and it is important that these losses should be maintained at a minimum.

Apart from the foregoing, one is aware that under the best conditions 60 tons of water have to be evaporated in the production of every 40 tons of ammonium sulphate. In other words, $1\frac{1}{2}$ tons of water have to be evaporated per ton of sulphate of ammonia manufactured. Against this disadvantage, no steam is required for the distillation of the concentrated gas liquor, such as would be involved if concentrated gas liquor were to be used in conjunction with sulphuric acid in the manufacture of ammonium sulphate.

Without attempting to enter into detailed calculations, it will be assumed that the one advantage offsets the other disadvantage.

Regarding the matter from the point of view of chemical plant, it is clear that a good deal more apparatus is required in connection with the anhydrite process than with that involving the use of sulphuric acid.

The anhydrite process involves crushing, grinding, and

screening plant; reaction vessels with agitators and suitable drives for the interaction; purification plant for the flue gases containing CO_2; special filter presses, together with vacuum producing plant for the separation of the calcium carbonate sludge from the ammonium sulphate solution; plant for the evaporation of ammonium sulphate solution, and rotary dryers for the treatment of the calcium carbonate sludge.

Where concentrated gas liquor is used, and sulphuric acid is the source of the SO_3 ion in the manufacture of ammonium sulphate, a gas liquor still with heat interchangers and coolers, and a saturator and equipment, are the only plant involved.

3. Coming now to the cost of anhydrite, having regard to the unit processes involved, in contrast with the price of sulphuric acid.

It is known that anhydrite containing (say) 90 per cent. of calcium sulphate, can be obtained in the neighbourhood of the mines at 12/6 per ton, but delivered London or the equivalent, it will cost 25/- per ton.

How far the anhydrite process is likely to prove advantageous depends largely on the geographical situation of the ammonia works in relation to the anhydrite mines. The following estimates will doubtless prove interesting, representing, as they do, a pecuniary comparison of anhydrite (*a*) under the best conditions, and (*b*) under conditions obtaining in London, as contrasted with the price of sulphuric acid.

Example (*A*): Estimate based per ton of ammonium sulphate manufactured, containing 25.5 per cent. NH_3.

	£	s.	d.
(*a*) 24 cwt. of anhydrite at 12/6 per ton at mines, plus 2/6 per ton carriage=15/- per ton		18	0
(*b*) Grinding of 24 cwt. of anhydrite at 4/- per ton		4	10
(*c*) Extra cost for power and labour for filtration and handling the calcium carbonate sludge ...		5	0
(*d*) Interest at 5 per cent. and depreciation at 7½ per cent. on extra capital cost of plant, say		4	0
(*e*) Extra chemical supervision		3	6
(*f*) Cost of treatment of flue gases for carbonatation process		2	6
(*g*) Water for cooling and washing precipitated calcium carbonate cake		2	6
	£2	0	4

Against the above, where sulphuric acid is used, one has the following charge :—

1.11 tons of 70 per cent. acid at (say) 55/- per ton	£3 1 0
Difference in favour of the anhydrite process, per ton of ammonium sulphate manufactured	£1 0 8

Example (*B*) : Estimate based per ton of ammonium sulphate manufactured, containing 25.5 per cent. NH_3.

	£	*s.*	*d.*
(*a*) 24 cwt. of anhydrite at 25/- per ton, delivered London, or equivalent	1	10	0
(*b*) This item is identical with example (*a*) ...		4	10
(*c*) „ „ „ „ ...		5	0
(*d*) „ „ „ „ ...		4	0
(*e*) „ „ „ „ ...		3	6
(*f*) „ „ „ „ ...		2	6
(*g*) „ „ „ „ ...		2	6
	£2	12	4

Against the above, where sulphuric acid is used, one has the following charge :—

1.11 tons of 70 per cent. acid at (say) 55/- per ton	£3 1 0
Difference in favour of the anhydrite process per ton of ammonium sulphate manufactured ...	8 8

The comparison afforded by the two foregoing statements is as accurate as the writer's experience will admit of. The figures show an advantage of 20/8 per ton, where anhydrite can be obtained favourably, and 8/8 per ton where the ammonia works is situated in London, or the equivalent.

It is obvious, therefore, that the anhydrite process as an alternative to the use of sulphuric acid, needs to be carefully considered. The nature of the process, however, necessitates a medium-sized scale of operations, and it is the writer's view that plant to produce *less* than 30 to 40 tons of ammonium sulphate per day would not be warranted.

Only one further comment is called for. Where the centrally situated chemical works is sufficiently large, it would, perhaps, be advisable to consider a process which involved the manufacture

of diammonium phosphate and calcium nitrate from (*a*) concentrated gas liquor, (*b*) ground phosphate rock treated with sulphuric acid in the manufacture of phosphoric acid, and (*c*) the utilisation of the precipitated calcium sulphate (which is really in a better form physically than anhydrite), in the production of ammonium sulphate.

Incidentally, the calcium carbonate produced from the latter process could be treated with nitric acid obtained by the oxidation of ammonia (Ostwald process), to yield calcium nitrate and release carbon dioxide for the carbonatation process.

One such cyclic process, possessing distinctive features, has been suggested by Dorr-Liljenroth, and it is certain that more will be heard of the process in the near future.

As far as one can ascertain from a consideration of railway rates and other related data, the radius covered by any centrally-situated chemical works treating concentrated gas liquor or ammonium sulphate solution should not be more than forty miles.

ZUSAMMENFASSUNG

Die Herstellung von Ammoniumverbindungen auf wirtschaftlicher Grundlage ist ein Problem der Gegenwart. Die starke Zunahme in der Erzeugung von Ammoniumsulfat aus synthetischem Ammoniak sowie der daraus folgende Verkaufspreisrückgang gestalten das Problem sehr akut. Es entsteht die Frage, wieso es mehr kostet, Ammoniak aus Stadtgas zu gewinnen als es in einer teuren Anlage mit einem komplizierten Verfahren zu erzeugen. Der Verfasser gibt keine direkte Antwort auf diese Frage sondern untersucht einige technische und wirtschaftliche Probleme, die uber die aufgeworfene Frage einige Auskunft zu geben in der Lage sind.

NEUE METHODEN DER BRENNSTOFFUNTERSUCHUNG

(NEW METHODS OF FUEL ANALYSIS)

DEUTSCHER VEREIN VON GAS- UND WASSERFACHMÄNNERN

PROF. DR. BUNTE

*Paper No. H*14

CONTENTS

ENGLISH TRANSLATION

Seit Jahrzehnten gilt unverändert als übliches Schema für die Untersuchung der festen Brennstoffe:

Asche,
Wasser,
Reinbrennstoff,

Verkokungsrückstand,
Flüchtige Bestandteile,

Elementaranalyse,

Verbrennungswärme,
Heizwert.

Nach diesem Schema liegt umfangreiches Untersuchungsmaterial vor; also sollte man annehmen, es müssten sich mit Leichtigkeit für einen bestimmten Zweck die geeigneten Brennstoffe auswählen oder angeben lassen. Man kommt aber meist in ziemliche Verlegenheit, wenn man über den technischen oder wirtschaftlichen Wert auf Grund solcher Unterlagen bestimmte Angaben machen soll.

Fast ebensolange, als dieses Schema eingeführt ist, besteht bekanntlich auch die Erkenntnis, dass die Menge der Asche deren schädlichen Einfluss durchaus nicht voll darstellt, dass die Beurteilung des Tiegelkokses die Verkokungseigenschaften nur teilweise und nur sehr subjektiv wiedergibt, dass die Elementaranalyse zwar für die allgemeine Charakterisierung und für die Berechnung der Verbrennungsprodukte wichtig ist, aber selbst in der Umrechnung auf Reinkohle kaum die Gleichheit zweier Brennstoffe, keinesfalls aber mit Sicherheit die Herkunft selbst festzustellen erlaubt, dass endlich der Heizwert den brenntechnischen Wert nur sehr mangelhaft erfasst.

Die neuere Brennstofforschung hat zu einer Reihe von Laboratoriumsmethoden geführt, die geeignet sind, das in vielen, um nicht zu sagen, den meisten Fällen, unzulängliche Schema der Brennstoffuntersuchung allgemein oder von Fall zu Fall zu ergänzen.

Das Gasinstitut ergänzt:

1.—*die qualitative Ascheebestimmung*
  (*a*) durch die Bestimmung des Kegelschmelzpunktes,
  (*b*) neuerdings durch die Feststellung der Schmelzkurven,

2.—*die übliche Wasserbestimmung* in gewissen Fällen durch die Xylolmethode,

3.—*die Verkokungsprobe*
  (*a*) durch die Blähprobe,
  (*b*) die Feststellung des Backvermögens,
  ferner ist die Bestimmung der Verkokungswärme und die Feststellung des Anteils an koksbildenden Bestandteilen in Vorbereitung.

4.—*die flüchtigen Bestandteile*
  (*a*) bei Gaskohlen durch die Bestimmung der Heizwertzahl des Gases,
  (*b*) bei Schwelkohlen durch die Schwelanalyse,

5.—*den Heizwert*, soweit es sich um Verkokungsprodukte handelt, durch die Bestimmung der Reaktionsfähigkeit,

6.—*bei der Elementaranalyse der Reinkohle* endlich halten wir es für richtiger, den überwiegend anorganischen Schwefel aus der Umrechnung ganz auszuschalten, falls man sich nicht aus besonderen Gründen der grossen Mühe unterziehen will, den organischen Schwefel für sich zu bestimmen.

Wir erheben durchaus nicht den Anspruch darauf, damit neue Wege zu gehen; wir halten es aber für wichtig, diese Ergänzung im weiteren Kreise zur Diskussion zu stellen; denn die Bestimmungen werden um so wertvoller, je schneller die Brennstofftechnik über möglichst zahlreiche Ergebnisse zum Vergleich verfügt.

Um das zu fördern, muss die Erkenntnis von der Zweckmässigkeit und u.U. Notwendigkeit dieser Ergänzungen aber auch in weitere Kreise der Brennstoff*verbraucher* getragen werden. Diese Erkenntnis ist durchaus noch nicht allgemein. Der Auftraggeber, welcher einen Brennstoff zur Untersuchung einsandte, ist vielmehr in den meisten Fällen sehr überrascht, wenn sich das beauftragte Laboratorium die neugierige Frage erlaubt, welchem Verwendungszweck der Brennstoff dienen soll oder gedient hat, um die Unter suchung über das Schema hinaus zu ergänzen. Vorschläge, die Untersuchung von Fall zu Fall durch obige Feststellungen zu ergänzen, bedürfen einer ausführlichen Erklärung, damit ihre Zweckmässigkeit und ihr Wert anerkannt und nicht etwa vermutet wird, das Laboratorium wolle nur seine Gebühren erhöhen. Je häufiger diese Bestimmungen ausgeführt werden, um so sicherer wird das Urteil der Laboratorien und später auch der Verbraucher werden und der Vergleichsmasstab zwischen Laboratoriumsbefund und Betrieb sich ergeben, nachdem beurteilt werden kann, welche Werte als normal, welche als bedenklich schlecht und als besonders gut zu bezeichnen sind.

Wenden wir uns den einzelnen Methoden zu:

Verhalten der Asche: Die Mehrzahl der Laboratorien stellt den Ascheschmelzpunkt und Erweichungspunkt an kegelförmigen Probekörpern fest.[1] Sinnatt[2] verwendet kleine, aus der Asche geformte Stäbchen und kommt im Wesentlichen zu ähnlichen Ergebnissen. Fulweiler, Burgess[3] u.a. schmelzen die Asche auf einem Platinblech, sogen. Mikropyrometermethode, und kommen zu erheblich abweichenden Ergebnissen. (Abb. 1.) Von ausschlaggebendem Einfluss erwies sich die oxydierende und reduzierende Atmosphäre.[4] Die Abb. 1 und 2 zeigen die mit 7 amerikanischen Ascheproben vom Bureau of Mines festgestellten Schmelz- und Erweichungspunkte mit unseren ebenfalls an Kegeln festgestellten im Vergleich. Die Abweichungen sind namentlich bei der Mikropyrometermethode ziemlich bedeutend.

Der Erweichungsvorgang ist bei fast allen Aschen stark verschieden und da er wohl noch grösseren Einfluss auf das Verhalten der Asche in der Feuerung hat, als der eigentliche Schmelz- bezw.

[1]Constam, Gasjournal 1913, S.1160.
Fieldner, Hall, Feild, U.S. Bureau of Mines Bull.129,1918.
Endell, Glückauf 1925, S.1179.
[2]Sinnatt, Owles, Simpson, Journ. Soc. Chem. Ind. 1923, S.266.
[3]Burgess, Bur. of Standards. Sci. Pap. 198, 1913.
[4]Selvig, Fieldner, Fuel 5, 1926, S.29.

Erweichungspunkt, verfolgten Bunte und Baum[5] im Gasinstitut diese Erweichung nach einer neuen Methode, die ausserdem gute Reproduzierbarkeit (5-8°C) und objektive Beobachtung miteinander verbindet. (Abb. 6.)

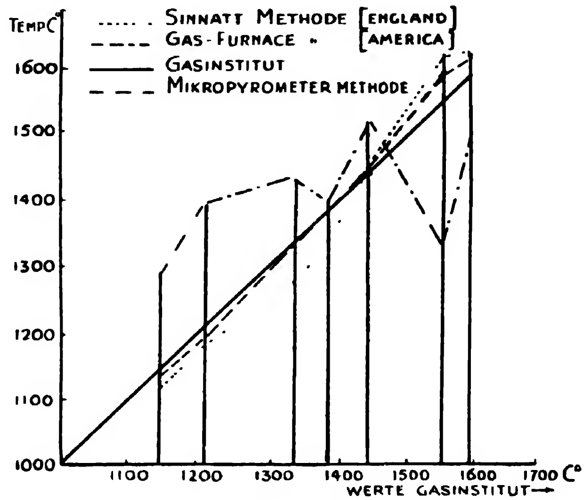

Abb. 1.—Vergleich der Aschenschmelzpunkte.

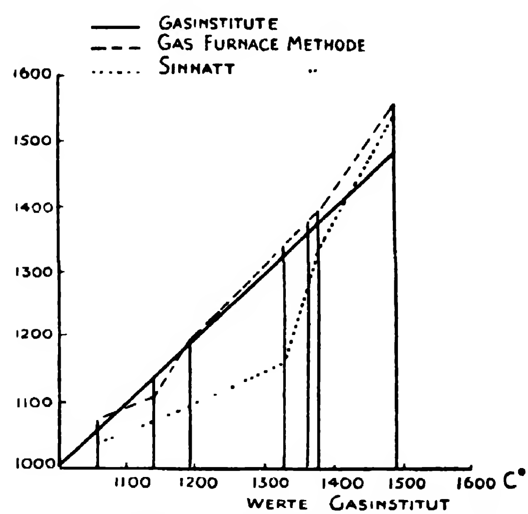

Abb. 2.—Vergleich der Erweichungspunkte.

Ein zylindrischer Probekörper wird im elektrischen Ofen in reduzierender Atmosphäre bei absolut gleichmässigem Temperaturanstieg zum Erweichen und Schmelzen gebracht und durch einen nur berührend aufsitzenden Graphitstab wird das Zusammensinken

[5]Gas- und Wasserfach 1928, Heft 5 u.6.

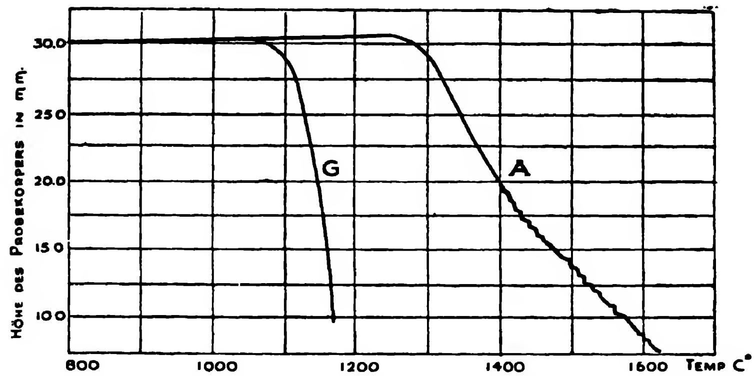

Abb. 3.—Schmelzkurven I. Gruppe.

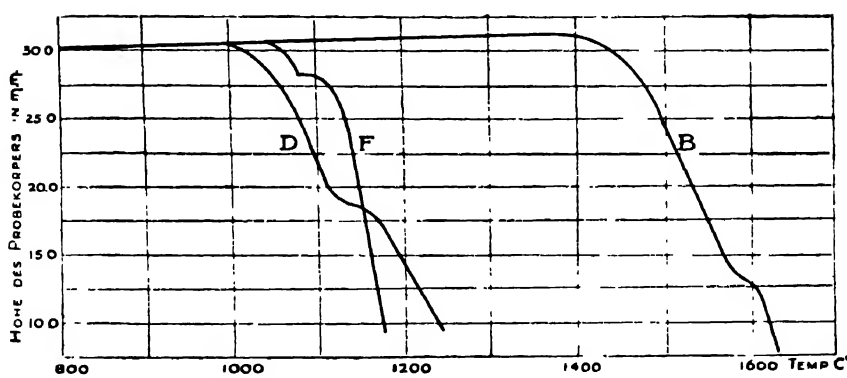

Abb. 4.—Schmelzkurven II. Gruppe.

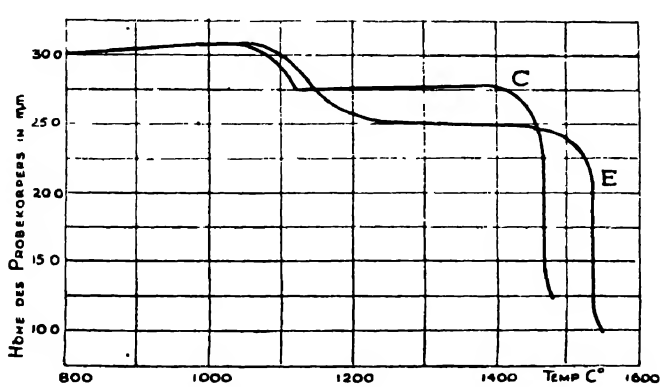

Abb. 5.—Schmelzkurven III. Gruppe.

graphisch aufgezeichnet. Die Erweichungskurven der 7 Aschen sind in den Kurventafeln 3-5 vereinigt. Sie zeigen, dass der Erweichungsvorgang auf drei grundsätzlich verschiedene Arten vor sich gehen kann. Einheitliches rasches Schmelzen zum Glasfluss zeigt nur die Asche G und eine gleichmässige langsame Erweichung die Asche A. Letztere Kurve ist nicht glatt, was sich aus der nachweislichen Entwicklung von Phosphorsäuredämpfen während des Schmelzens erklärt, die zur Gasblasenbildung während des Zusammensinkens des Probekörpers führt. Aschen, welche der Asche G ähnlich sind, werden zwischen Erweichungspunkt und Schmelzpunkt kaum einen Unterschied zeigen. Bei Aschen ähnlich A wird das Urteil über Erweichungs- und Schmelzpunkt sehr unsicher sein. Immerhin liegen in beiden Fällen einigermassen einheitliche Aschen vor.

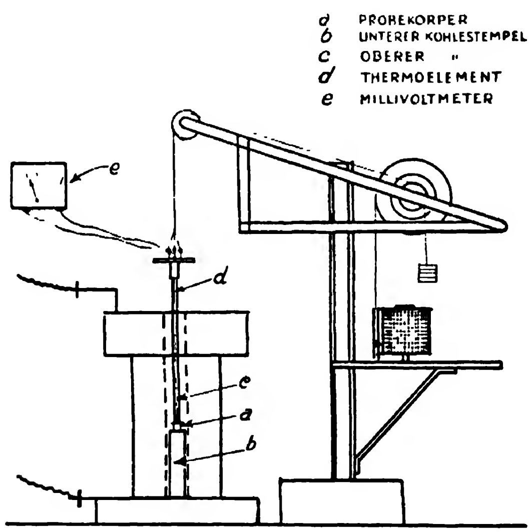

Abb. 6.—Apparatur zur Aufnahme der Schmelzkurven nach Bunte-Baum.

Eine zweite Reihe ist durch die Kurven F, D und B charakterisiert, in denen zuerst ein teilweises Schmelzen, dann ein kurzes Anhalten und schliesslich mehr oder weniger rasches Schmelzen zum Glasfluss zu beobachten ist. Es muss vorläufig unentschieden bleiben, ob hier Seigerungserscheinungen oder Zwischensilikatbildungen vorliegen.

Wesentlich schärfer tritt dieses Anhalten bei den Aschen C und E zu Tage, bei welchen auf eine Teilschmelzung, die im praktischen Feuerungsbetrieb zum Verfritten der Asche führen kann, erst bei erheblich höherer Temperatur eine endgültige Schmelzung folgt.

Die neue Methode scheint uns erstens weitgehendere Schlüsse auf das Verhalten der Asche in der Feuerung zuzulassen als die Kegelschmelzpunkte; sie lässt zweitens auch Schlüsse zu auf die Einheitlichkeit der Asche.

Endlich kann die Silikatbildung aus den Oxyden auch auf die Verbrennlichkeit von Koksen grossen Einfluss gewinnen[6]. Geht der ursprünglich katalytisch wirkende Fe_2O_3-Gehalt oder -Zusatz mit steigenden Verkokungstemperaturen in ein Silikat über, so wird er über der Bildungstemperatur dieses Silikates katalytisch unwirksam[7].

Bei jungen, bitumenreichen Brennstoffen empfiehlt es sich nach einem Vorschlag von Schläpfer[8] die *Wasser*bestimmung nicht durch Gewichtsverlust beim Trocknen zu bestimmen, sondern das beim Erhitzen in Xylol entwickelte Wasser direkt zu messen. Dadurch werden Fehler vermieden, die sowohl durch Bitumenverlust ein Zuviel, als auch durch Gewichtszunahme infolge Oxydation ein Zuwenig an Wasser ergeben können und die sich bei der Umrechnung auf Reinbrennstoff auswirken. (Abb. 7.)

Die *Verkokungsprobe* ist je nach Art und Verwendungszweck des Brennstoffes verschieden zu ergänzen, für Koks- und Gaskohlen vor Allem durch eingehendere Feststellungen über die Elemente der Koksbildung, für Gas- und Schwelkohlen durch Ausbau der Bestimmung der flüchtigen Bestandteile.

Zur Ergänzung der mengenmässigen Koksausbeute durch Bestimmung des *Blähgrades* hat sich nach unseren Erfahrungen die Lessing'sche Blähprobe[9] bewährt. Sie ist an Einfachheit und Zweckmässigkeit anderen Methoden[10] überlegen.

Zur zahlenmässigen Festlegung der *Backfähigkeit* empfiehlt sich die Methode von Kattwinkel[11] nach welcher die feingepulverte Kohle (400er-Maschensieb) mit reinem ausgesiebtem Quarzsand im Verhältnis 1 : 10 gemischt, und die Druckfestigkeit und der nicht in

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[6]Lessing, Fuel 1926, S.117,
Wigginton, Fuel 1926, S.531,
Bähr, Stahl u.Eisen 1924, S.39,
Nettlenbusch, Brennstoffchem. 1927, S.37,
Cobb, Sutcliffe, Branson, Dent, Fuel 1927, S.449.
[7]Bähr u.Fallböhmer, Gas- u. Wasserfach 1926, S.909.
[8]Ztschr. f. angew. Chem. 27, 1914, S.52.
[9]Journ. Gaslighting, July 1912,
Fuel 1923, S.152/186.
[10]Schreiber, Stahl u.Eisen 1920, S.1278,
Korten, Stahl u.Eisen 1920, S.1105.
Lant, l.c.Strache-Lant, Kohlenchemie S.512.
[11]Gas- u. Wasserfach 1926, S.145.

den Kokskuchen aufgenommene Anteil zur zahlenmässigen Festlegung der Backfähigkeitszahl benutzt wird.

Während Meurice die Druckfestigkeit des Koks-Sand-Kuchens mittels einer Hebelpresse ermittelte, verbesserte Kattwinkel diese Methode, um eine stossfreie Drucksteigerung zu erreichen, dadurch, dass er ein neues Prüfgerät konstruierte, bei dem die Belastung gleichmässig ansteigt. Als Belastungsgewicht wird Tarierschrot (1-1,25 mm) benutzt, das aus einer 5 mm weiten Düse in ein geeignetes Belastungsgefäss ausströmt. Der sekundliche Lastzuwachs beträgt so 35 g/sec. (Abb. 8.)

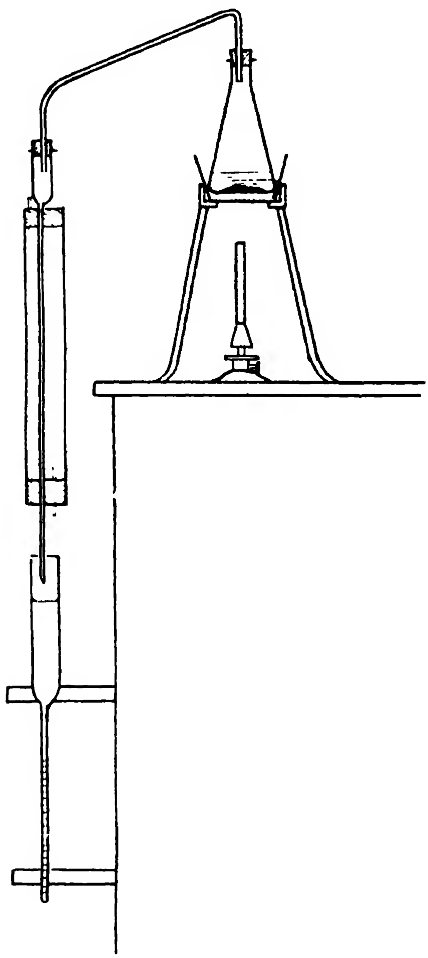

Abb. 7.—Apparatur zur Wasserbestimmung nach Schläpfer.

Die Bestimmung der *Verkokungswärme* gewinnt vor Allem für Leistungsversuche an Gaserzeugungsöfen an Bedeutung. Terres[12]

[12]Gas- und Wasserfach 1927, Heft 1-4.

definiert als Verkokungswärme "diejenige Wärmemenge in kcal die erforderlich ist, um 1 kg lufttrockene Kohle von 20°C in Koks bei irgendeiner Temperatur (z.B. 1 000°) zu verwandeln, bezogen auf Koks (von 1 000°) flüssiges Wasser und flüssigen Teer (von 20°) und einschliesslich der Energie in kcal, die der äusseren Arbeitsleistung der gasförmigen Entgasungsprodukte entspricht." Es ist also diejenige Wärmemenge, die theoretisch zur Durchführung der Verkokung erforderlich ist, die also mit dem praktischen Wärmeaufwand verglichen, den Wirkungsgrad einer Verkokungsanlage ergeben müsste. Die Verkokungswärme stellt daher eine Zahl von grosser technischer Wichtigkeit dar.

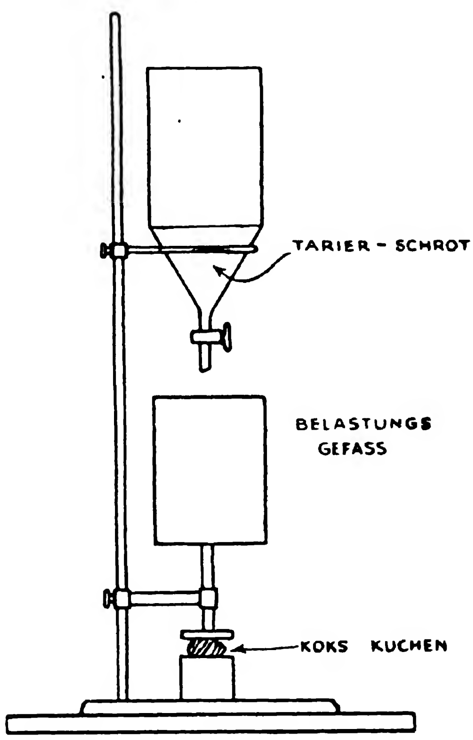

Abb. 8.—Apparatur zur Bestimmung der Druckfestigkeit des Kokssandkuchens nach Kattwinkel.

Die in der angeführten Arbeit beschriebene Methode und vor Allem auch die Berechnungsweise für die Verkokungswärme erfahren, wie Prof. Terres persönlich mitteilte, durch neuere Untersuchungen eine nicht unwesentliche Abänderung und Vereinfachung, die vor einer allgemeinen Einführung der Methode abgewartet werden muss.

Die mengenmässige Feststellung der Kohlenbestandteile, welche die kokenden Eigenschaften bedingen und ihres für den Schmelzvorgang offenbar ausschlaggebenden Verhältnisses gewinnt durch die gesteigerte Anwendung der Kohlen-Mahlung und -Mischung eine überragende Bedeutung. Alle Untersuchungen, die eine Voraussage des Mischungsergebnisses und damit die richtige Wahl der zu mischenden Kohlensorten und ihre Mengenverhältnisse ermöglichen, dürfen also der grössten Aufmerksamkeit sicher sein. Ob diese Voraussagen auf

(*a*) *Extraktionsversuche*, d.h. Bestimmung der α, β, γ Bestandteile[13] oder Unterscheidung von Oelbitumen und Festbitumen[14]

(*b*) *auf Scheidung von Vitrit, Clarit, Durit, Fusit*, nach dem spez. Gewicht[15]

zu beruhen haben werden, lässt sich heute wohl noch nicht so entscheiden, dass eine bestimmte Methode zur allgemeinen Einführung empfohlen werden könnte.

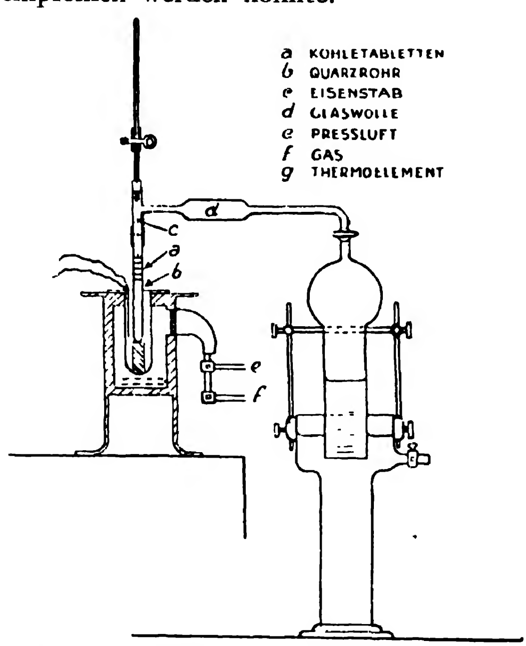

Abb. 9.—Apparatur zur Bestimmung der Heizwertzahl des Gases nach Geipert.

[13] Illingworth, Gas- u. Wasserfach 1923, S.225,
Wheeler, Journ. Chem. Soc. 1927, April,
Barash, Fuel 1927, S.532.

[14] Fischer und Gluud, Ges. Abhandl. d. Kohle, Bd. III, S.35,
Brennstoffchemie 1925, S.33 u.S. 349.

[15] Dorflinger, Kokereiausschuss d. Ver. dtsch. Eisenhüttenleute, Bericht 26,
Kattwinkel, Glückauf 1928, Heft 3.

Für die Gaskohlen hat sich die *Bestimmung von Gasausbeute und Heizwert des Gases* in einer von Geipert[16] (Abb. 9.) beschriebenen Apparatur vollständig bewährt. Die Kohle wird in Pastillen gepresst, die Pastillen gelocht und an einem Stab aufgereiht und an diesem in ein auf 1 100° erhitztes Entgasungsrohr aus Quarzglas eingeführt; der Teer wird durch ein Glaswollefilter zurückgehalten und das Gas in besonders geformten Glasmesskolben aufgefangen. Bei genauer Einhaltung der Kohlenmengen (10g), der Temperatur (1 100°) und der Abmessungen des erhitzten Rohres konnten wir eine überraschend vollständige Uebereinstimmung nicht nur zwischen den Einzelbestimmungen, den Werten verschiedener Beobachter und den Ergebnissen verschiedener Laboratorien, sondern auch mit den Ergebnissen der Entgasungsversuche im Betriebsmasstab feststellen.

Damit ist nicht nur eine wertvolle Bestimmungsmethode für die betriebliche Bewertung der Gaskohlen nach Heizwertausbeute, sondern auch eine reinliche Grundlage für Garantien über Gaserzeugungsöfen gewonnen. Während bisher eine gewisse Gasausbeute und Heizwertzahl unter der Voraussetzung einer "guten Gaskohle" mit bestimmtem Wasser- und Aschegehalt garantiert zu werden pflegte, wird es nunmehr möglich sein, die ' gute Gaskohle" durch die Heizwertzahl nach Geipert zahlenmässig festzulegen. Nach unseren Erfahrungen ist die Reproduzierbarkeit erheblich besser als nach der bisher hierfür angewandten wesentlich umständlicheren Destillation nach Bauer,[17] deren Wert für die Bestimmung der zu erwartenden Nebenprodukte im übrigen nicht in Zweifel gezogen werden soll.

Bei Schwelkohlen, insonderheit Braunkohlen, ist die *Schwelanalyse* bereits üblich; da sie aber auch für Generatorbrennstoffe wertvolle Auskünfte gibt, sollte sie viel allgemeiner angewandt werden. Die Aluminium-Schwelretorte nach Fischer und Schrader[18] hat sich im Gasinstitut ausgezeichnet bewährt. (Abb. 10.)

Mit dem fortschreitenden Ausbau der Generatortechnik und der Brennstaubfeuerung gewinnt neben dem Heizwert die *Reaktionsfähigkeit* verkokter Brennstoffe ständig wachsende Bedeutung. Der Aufklärung dieser typischen und für die Vorgänge im Brennstoffbett wesentlich bedingenden Eigenschaft der

[16]Gas- und Wasserfach 1926, S.861.
[17]Journal für Gasbeleuchtung 1913, S.389.
[18]Ztschr. f. angew. Chem. 1920, S.172, Brennstoffchemie 1920, S.87.

ENTGASUNGS-ERGEBNISSE NACH METHODE GEIPERT

Kohlen-Sorte	Herkunft		Laboratorium: Gasinstitut Brennstoff-Laboratorium: Gas m³ 0° 760 mm	Laboratorium: Gasinstitut Brennstoff-Laboratorium: Heizwert kcal/m³ 0° 760 mm	Laboratorium: Gasinstitut Brennstoff-Laboratorium: Heizw.-Zahl für 100 kg Reinkohle	Laboratorium: Laboratorium Dr. Geipert: Gas m³ 0° 760 mm	Laboratorium: Laboratorium Dr. Geipert: Heizwert kcal/m³ 0° 760 mm	Laboratorium: Laboratorium Dr. Geipert: Heizw.-Zahl für 100 kg Reinkohle	Technischer Versuch: Versuchsgasanstalt Karlsruhe Horizontalretorte: Gas m³ 0° 760 mm	Technischer Versuch: Versuchsgasanstalt Karlsruhe Horizontalretorte: Heizwert kcal/m³ 0° 760 mm	Technischer Versuch: Versuchsgasanstalt Karlsruhe Horizontalretorte: Heizw.-Zahl für 100 kg Reinkohle	Technischer Versuch: Garantieversuch Kokerei Düsseldorf: Gas m³	Technischer Versuch: Garantieversuch Kokerei Düsseldorf: Heizwert kcal/m³	Technischer Versuch: Garantieversuch Kokerei Düsseldorf: Heizw.-Zahl für 100 kg Reinkohle
Dahlbusch-Zollverein (Mischung 1 : 1)	Ruhr		34,6	5 500	1 904	34,5	5 500	1 898	34,4	5 500	1 892	36,1	5 285	1 909
Gleiwitz ...	O.S.		34,8	5 510	1 920	34,9	5 520	1 925	36,4	5 430	1 976	—	—	—
Königin Luise ...	O.S.	(a)	34,9	5 372	1 875	35,2	5 180	1 825	37,2	5 230	1 878	—	—	—
		(b)	35,5	5 189	1 843	—	—	—	—	—	—	—	—	—
Bahnschacht ...	O.S.	(a)	35,3	5 272	1 860	32,5	5 180	1 825	37,2	4 943	1 835	—	—	—
		(b)	36,8	5 140	1 890	—	—	—	—	—	—	—	—	—
Graf Bismarck ...	Ruhr		33,2	5 784	1 920	—	—	—	36,4	5 365	1 955	—	—	—

(a) = Beobachter I.
(b) = Beobachter II.

Verkokungsprodukte hat sich zwar die Forschung mit grossem Interesse zugewandt.[19]

Die Technik und die Brennstoffuntersuchung hat sie aber noch nicht in ausreichendem Masse als eine der Immediatanalyse und der Heizwertbestimmung zum mindesten an Wichtigkeit gleichstehende, in vielen Fällen sie an Bedeutung überragende Eigenschaft anerkannt. Die wichtigen Feststellungen von Clement, Adams und Haskins[20] sind z.B. mehr als ein Jahrzehnt lang fast

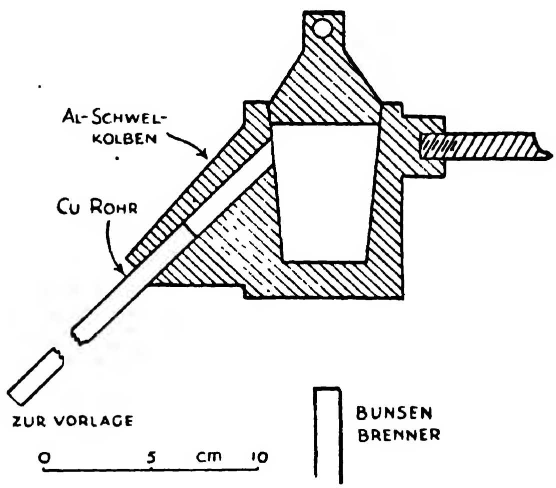

Abb. 10.—Al.-Schwelretorte nach Fischer.

völlig in ihrer Bedeutung übersehen worden. Das Verhalten von Koksen im Generatorgaserzeuger und bei der Wassergaserzeugung, die Rückzündfähigkeit auf dem Wanderrost, die Brennlänge bei der Kohlenstaubflamme und endlich z.B. auch die richtige Wahl der Feuerungsanordnung bei Zentralheizungskesseln—Oberfeuer oder Unterfeuer—sind von der Reaktionsfähigkeit des Kokses abhängig.[21]

Wir haben im Gasinstitut, als wir uns mit dieser Eigenschaft und ihrer zahlenmässigen Festlegung zu beschäftigen begannen, zuerst

[19] Koppers-Mitteilungen 1923, Heft 2,
Chimie et Industrie 1923, Vol. 8, Nr. 1,
Fischer, Brennstoffchemie 1923, S.33,
Häusser & Bestehorn, Ges. Unters. üb. d. Verbrennlichkeit von Hüttenkoks,
Agde & Schmitt, Red. Fähigkeit von Steinkohlenkoks, Knapp-Halle,
Mezger & Pistor, "Die Reaktionsfähigkeit des Kokses," Knapp-Halle.
[20] Bureau of Mines, Bull. 7, 1911.
[21] Kreulen, Brennstoffchemie 1926, S.54,
Korevaar, Stahl u.Eisen 1923, S.431,
Follmann, Feuerungstechnik 1927, S.205.

eine Methode in Vorschlag gebracht, welche die Reaktionsfähigkeit gegen Sauerstoff, also den Zündpunkt als Charakteristikum wählte.[22] Wir haben uns inzwischen gelegentlich von Arbeiten über die Parallelität von Zündpunkt und Reaktionsfähigkeit überzeugt, dass die Reaktionsfähigkeit gegen CO_2 experimentell ebenso einfach zu bestimmen ist und diese wichtige Eigenschaft anschaulicher und überzeugender wiedergibt. Wir haben uns, um der raschen Vereinheitlichung der Methode zu dienen, entschlossen, die von Koppers[23] vorgeschlagene und von einigen Verbraucherstellen angenommene Methode anzuwenden, nach der reines CO_2 bei 1 000° mit einer Geschwindigkeit von 30 ccm/min in einem Rohr von 5-6 mm ϕ über 1 g Koks (0,5-1 mm Körnung) geleitet und die Reaktionsfähigkeit als Verhältnis des in CO umgewandelten zum angewandten CO_2 ausgedrückt wird,

$$\frac{CO \times 100}{CO_2 + \frac{CO}{2}}$$

Die Bestimmung lässt sich auf diese Weise in ungefähr 2 Stunden erledigen. (Abb. 11.)

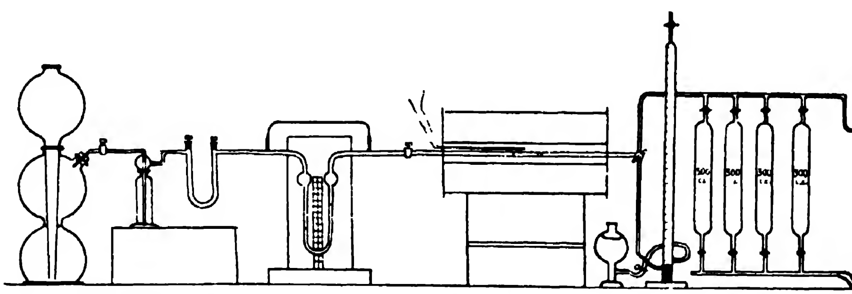

Abb. 11 —Apparatur zur Bestimmung der Reaktionsfähigkeit.

Die Reaktionsfähigkeiten werden nach unserer bisherigen Erfahrung etwa durch folgende Werte wiedergegeben:

Holzkohle	zwischen	135	und	145
Grude	„	180	„	190
Halbkoks	„	125	„	130
Gaskoks (Retorte)	„	80	„	115
„ (Kammer)	„	60	„	90
Zechenkoks	„	30	„	80

Die vollständige Umsetzung würde naturgemäss 200 ergeben.

[22]Bunte u.Kölmel, Gas- u. Wasserfach 1922, S.593,
Bunte u.Fitz, Ratzel, Gas- u. Wasserfach 1926, S.192 u. 217.
[23]Ztschr d. V D. I. 1925 S.531.

Wir halten es für eine Aufgabe der Weltkraftkonferenz, einen Meinungsaustausch über die Erweiterung der Kohlenuntersuchungsmethoden einzuleiten und geben daher unsere Erfahrungen als Anregung bekannt. Vor Allem aber halten wir es für nötig, dass die Erkenntnis über die Fortschritte der modernen Brennstoffuntersuchung und über die Zweckmässigkeit und Notwendigkeit der Ergänzung des bisherigen Schemas in weitere Kreise der Brennstoffverbraucher getragen wird.

NEW METHODS OF FUEL ANALYSIS

PROF. DR. BUNTE

(English Translation)

For upwards of fifty years the ordinary scheme of investigation of solid fuels has always comprised the following determinations:

Ash,
Water,
Combustible matter,
Coke,
Volatile matter,
Ultimate analysis,
Calorific value (gross and net).

Very copious data are available on the above lines; one might, therefore, assume that from such data it would be easy to select or indicate the most suitable fuels for any definite purpose. Usually, however, it is rather embarrassing to be asked to make definite statements on the technical or economic value of a fuel on the basis of such data.

It is well known that, almost from the time when the above scheme of investigation was first introduced, it was realised that the actual percentage of ash by no means fully indicates its prejudicial effect, that the determination of the yield of coke only partially and very subjectively indicates the coking properties, that the ultimate analysis is certainly of importance for calculating the amounts of the products of combustion, but that even when recalculated for pure coal it hardly enables conclusions to be drawn as to the identity of two fuels, and certainly does not enable unequivocal conclusions to be drawn as to their origin; finally, it was realised that a knowledge of the calorific value provides very dubious information as to the value of the coal for technical heating purposes.

Recent research on fuels has led to a number of laboratory methods which are capable in many, if not in most, cases of completing the partial scheme of fuel analysis.

The Gas Institute completes the scheme as follows:—

1.—*Ash:*—

(*a*) By the determination of the melting point by means of cones.

(*b*) Recently, by the determination of the melting point curves.

2.—*The usual determination of water* by the xylene method in special cases.

3.—*The coking test:*—

(*a*) By the determination of the coke volume (Lessing's test).

(*b*) By the determination of coking power.

Moreover, preliminary work has been done on the determination of the heat of carbonisation, and on the determination of the percentage of coke-forming constituents.

4.—*Volatile matter:* This is supplemented:—

(*a*) in the case of gas coals by the determination of the calorific multiple of the gas.

(*b*) In coals suitable for low-temperature carbonisation by the low-temperature assay test

5.—*The calorific value of coke* by the determination of the reactivity.

6.—*Ultimate analysis of the coal:* -

When recalculating this in terms of pure coal, in view of the fact that the sulphur is mainly present in inorganic form, we consider it more correct to leave this out of account except in those cases where for special reasons the considerable amount of work is undertaken which is necessary in order to determine the organic sulphur separately.

We in no way claim that in these matters we are pursuing new paths, but we consider it important that these supplementary methods should be discussed in wider circles, for such determinations become progressively more valuable with the accumulation of data providing a basis for comparison by fuel technologists.

In order to promote such a result, the recognition of the utility and even of the necessity of these supplementary methods must also be brought home to wider circles of actual consumers of fuel. Such a recognition is by no means general at present. The client who submits a fuel for investigation is, on the contrary, usually very surprised if the laboratory entrusted with the investigation ventures to put an inquisitive question as to the purpose which the fuel is intended to serve or has served, so that it may complete the investigation beyond the limits of the ordinary methods. Proposals to extend investigations in one case or another by the above-mentioned supplementary methods must be accompanied by a detailed explanation so that their utility may be recognised and so that it may be realised that the motive of the laboratory is not merely to increase its fees. The more often such determinations are carried out the more confident will be the opinion expressed by the laboratories, and even by the consumer at a later date, and the more rapidly will a basis of comparison be found between laboratory and plant results, on the strength of which an opinion may be formed as to which values are normal and which values may be considered as bad or particularly good.

We will now turn to the individual methods.

1.—BEHAVIOUR OF THE ASH:

Most laboratories determine the melting point and softening point of the ash with the help of cone-shaped test bodies.[1] Sinnatt[2] uses small rods formed from the ash, and arrives at essentially the same results. Fulweiler, Burgess[3] and others melt the ash on platinum foil by the so-called "micro-pyrometer" method, and obtain results which differ considerably. (Fig. 1.) It was found that it is the oxidising or reducing nature of the atmosphere which mainly and markedly affects the results.[4] Figures 1 and 2 compare the determinations of the melting and softening points, respectively, of seven American samples of ash by the Bureau of Mines with the results obtained by us with cones. The deviations are rather considerable, more particularly in the results obtained with the micro-pyrometer method.

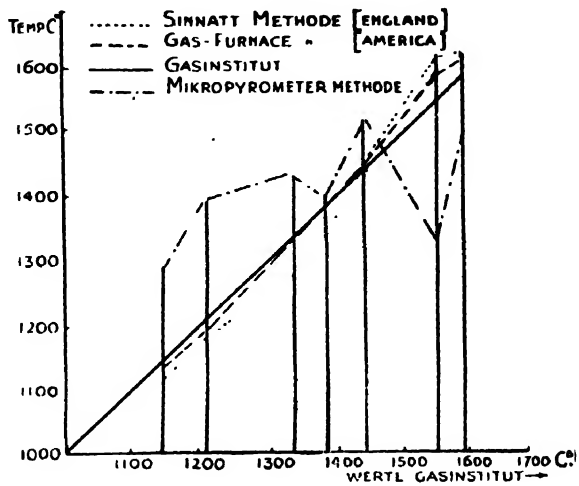

Fig. 1.—Comparison of melting points of coal ash.
Werte Gasinstitut = Values obtained by Gas Institute.

The phenomena of fusion vary very greatly from ash to ash, and since it is probably these which have a greater influence on the behaviour of the ash in the grate than has the actual melting or softening point, Bunte and Baum[5] investigated the phenomena in the Gas Institute by a new method, which not only gives consistent results (within 5° to 8° C.) but provides information of a valuable nature. (Fig. 6.)

A cylindrical test-piece is brought to the softening and melting points in an electric furnace in a reducing atmosphere at an absolutely constant rate of temperature rise. The subsidence of the sample is graphically recorded by means of a graphite rod in floating contact with the upper surface of the sample. The softening curves of the seven ashes are shown in figures 3 to 5. These show

[1]Constam. *Gas Journal* 1913, p. 1160;
Fieldner, Hall, Feild, *U.S. Bureau of Mines, Bull.* 129, 1918;
Endell, *Glückauf*, 1925, p. 179.
[2]Sinnatt, Owles and Simpson, *J. Soc. Chem. Ind.* 1923, p. 266.
[3]Burgess, *Bureau of Standards, Scientific Paper* 198, 1913.
[4]Selvig and Fieldner, *Fuel*, **5**, 1926, p. 29.
[5]*Gas- und Wasserfach*, 1928, Parts 5 and 6.

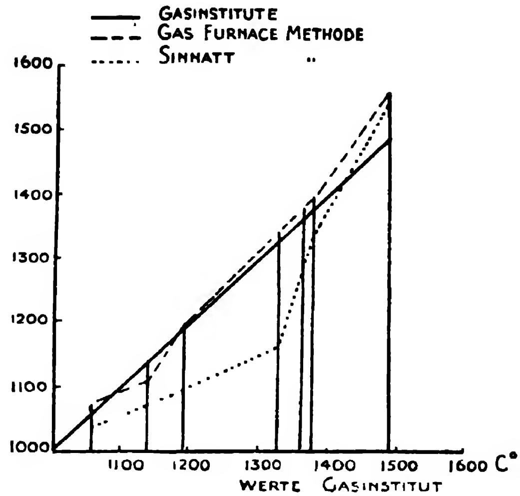

Fig. 2.—Comparison of softening points of coal ash.
Werte Gasinstitut = Values obtained by Gas Institute.

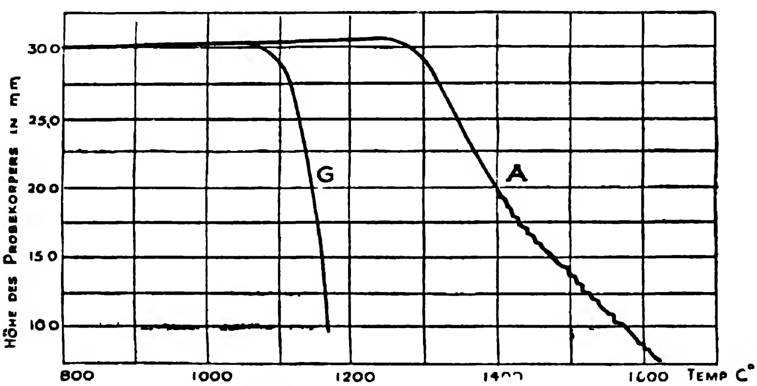

Fig. 3.—Melting point curves; Group I.
Höhe des Probekorpers in mm. = Height of test-piece in mm.

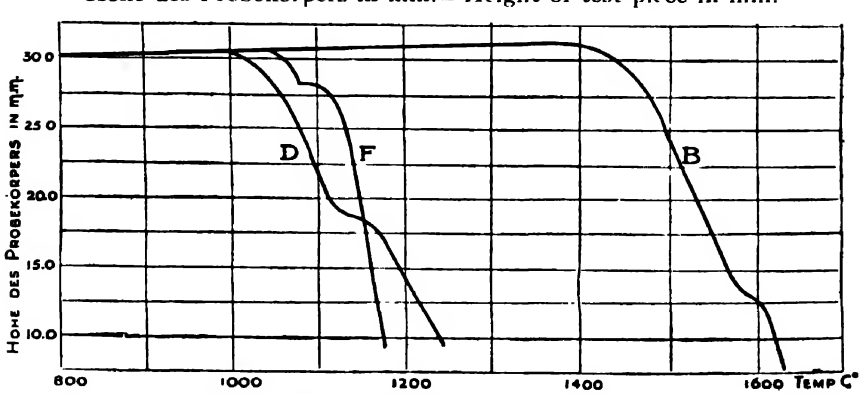

Fig. 4.—Melting point curves: Group II.
Höhe des Probekörpers in mm. = Height of test-piece in mm.

that the softening process may occur in three essentially different ways. A rapid melting to a molten glass is shown by ash G only, and a uniform slow softening by ash A. (Fig. 3.) The latter curve is not smooth; this may be explained by the observed evolution during the melting process of phosphoric acid vapours which lead to the formation of gas bubbles during the sintering of the test-piece. Ashes similar to G show scarcely any difference between the softening point and the melting point. For ashes similar to A it will be difficult to determine the exact softening and melting points. In both these cases the ashes are of relatively simple composition.

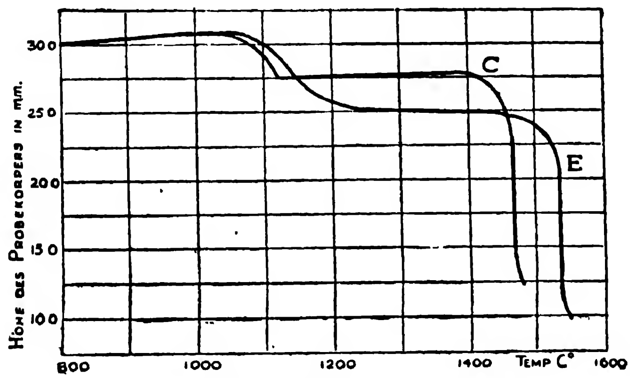

Fig. 5.—Melting point curves; Group III.
Höhe des Probekörpers in mm.= Height of test-piece in mm.

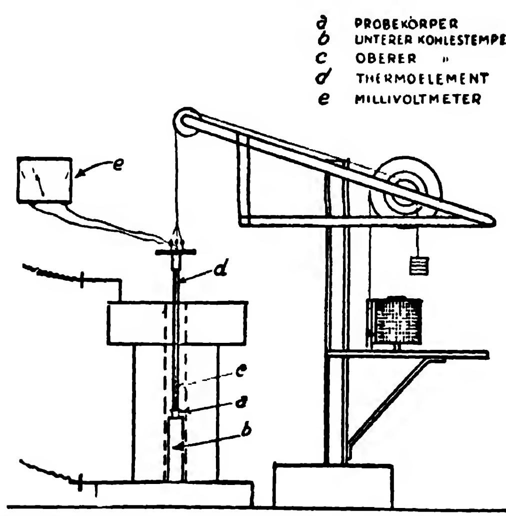

Fig. 6.—Bunte and Baum's apparatus for determining fusion curves.

(*a*) Test-piece.
(*b*) Support for test-piece.
(*c*) Rod resting on test-piece.
(*d*) Thermo-element.
(*e*) Millivoltmeter.

The second series is characterised by curves F, D and B (Fig. 4), which show partial melting, then a short pause, and, finally, more or less rapid melting to a fluid glass. For the time being, it is uncertain whether in these cases segregation occurs or intermediate formation of silicates.

The above behaviour is repeated in a greatly accentuated form in the case of ashes C and E (Fig. 5), in which a partial melting occurs which may lead to fritting of the ash under industrial firing conditions; it is only at a considerably higher temperature that actual fusion occurs.

The new method appears to us, first, to enable conclusions of a more far-reaching nature to be drawn as to the behaviour of the ash in the grate than does the ordinary cone melting point method; secondly, it enables conclusions to be drawn as to the degree of complexity of the ash. Finally, the formation of silicates from oxides may also have a considerable influence on the combustibility of cokes [6]

Iron oxide while in the form of Fe_2O_3 has a catalytic action, whether it is present as a natural constituent of the ash or as an artificially introduced constituent, but if it is converted into a silicate, consequent on an increase in the coking temperature, it will become catalytically inactive at temperatures above which such a silicate is formed.[7]

2.—DETERMINATION OF WATER:

For determining the water in the geologically young, highly bituminous fuels, it is advisable, as proposed by Schläpfer,[8] not to ascertain the loss of weight on drying, but to make an actual measurement of the water evolved when the fuel is heated in xylene. By this means errors are avoided which may otherwise occur in the form of a positive error through loss of bitumen, or of a negative error through increase of weight of the residue due to oxidation. Such errors affect the recalulated composition of the ash-free fuel. (Fig. 7.)

3.—THE COKING TEST:

This should be supplemented according to the character of the fuel and the purpose for which it is to be used. In the case of coking coals and of gas coals especially, it should be supplemented by a more comprehensive investigation of the coke-forming constituents, and in the case of gas coal and of fuel to be submitted to low-temperature carbonisation, by a determination of the yields of volatile products.

According to our experience, the determination of the yield of coke by weight is best supplemented by the determination of the coke volume by Lessing's swelling test.[9] It is simpler and more practical than other methods.[10]

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[6] Lessing, *Fuel*, 1926, p. 117;
Wigginton, *Fuel*, 1926, p. 531;
Bähr, *Stahl u. Eisen* 1924, p. 39;
Nettlenbusch, *Brennstoff-Chem.*, 1927, p. 37.
Cobb, Sutcliffe, Branson, Dent, *Fuel*, 1927, p. 449.

[7] Bähr and Fallböhmer, *Gas- und Wasserfach*, 1926, p. 909.

[8] *Ztschr. f. angew. Chem.* **27**, 1914, p. 52.

[9] *Journal of Gas Lighting*, July 1912;
Fuel, 1923, pp. 152-186.

[10] Schreiber, *Stahl u. Eisen*, 1920, p. 1278;
Korten, *Stahl. u. Eisen*, 1920, p. 1105.
Lant, *loc. cit.*;
Strache-Lant, *Kohlenchemie*, p. 512.

In order to determine the coking power numerically, the method of Kattwinkel is to be recommended.[11]

The finely powdered coal (which has been passed through a 400-mesh sieve*) is mixed with pure sifted quartz sand in the proportion of 1 : 10; the mixture is carbonised and the value obtained for the compressive strength of the coke-cake and the weight of the powder not forming part of the coke-cake are

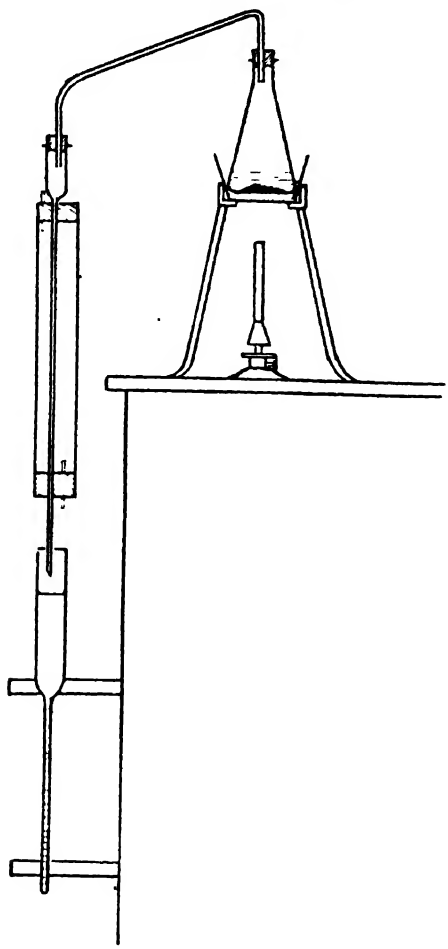

Fig. 7.—Schläpfer's apparatus for the determination of water.

used for the numerical evaluation of the coefficient of coking. Whereas Meurice determined the compressive strength of the cake of coke and sand by means of a lever press, Kattwinkel improved on this method by providing for a steady pressure increase by means of a new testing machine in which the load is increased uniformly. Shot of 1 to 1·25 mm. diameter is used for the load and is poured into a suitable container through a jet 5 mm. wide. The rate of increase of load is 35 gm. per second. (Fig. 8.)

[11] *Gas- und Wasserfach*, 1926, p. 145.
*A sieve having 400 meshes per sq. cm.

The determination of the heat of carbonisation is of increasing importance in connection with efficiency tests on carbonising plant. Terres[12] defines heat of carbonisation as "that quantity of heat in Kg. calories which is required to convert 1 Kg. of air-dried coal at 20°C. into coke at any specified temperature —for example, 1,000° C.—calculated on the basis of coke at 1,000° C., and liquid water and liquid tar at 20° C., and including the energy in Kg. calories which corresponds to the external work performed by the gaseous products." It is thus that quantity of heat which is theoretically necessary for carrying out the coking process and by comparison of which with the practical heat requirements the efficiency of a carbonising plant can be measured. The heat of carbonisation thus represents a figure of great technical importance.

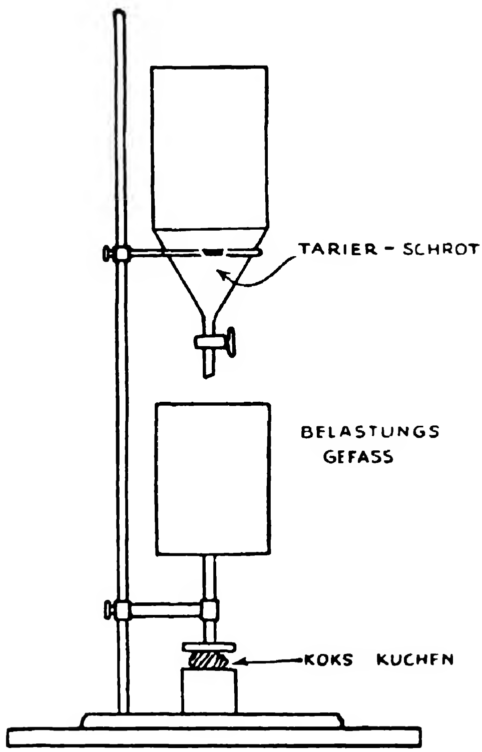

Fig. 8.—Kattwinkel's apparatus for the determination of the compressive strength of the cake of coke and sand.

Tarier-Schrot = Shot for applying load.
Belastungs-Gefass = Vessel for applying load.
Koks-Kuchen = Cake of coke.

According to a personal communication by Prof. Terres, the methods of measurement and calculation employed in determining the heat of carbonisation, as described in the above mentioned article have been appreciably altered and simplified as a result of more recent investigations, the publication of which must be awaited before the method can come into general use.

[12] *Gas- und Wasserfach*, 1927, Parts 1-4.

The quantitative determination of those constituents of the coal which are responsible for the coking properties and of their behaviour, which is evidently of prime importance in the melting process, has attained the highest importance through the increased extent to which coal is ground and blended. All investigations which make it possible to predict the results of a given admixture, and, consequently, the right choice of the proportions and qualities of coal to be mixed, will certainly attract the greatest attention. Whether such predictions will be based on:

(*a*) *extraction methods*, that is, the determination of the α, β and γ constituents,[13] or the separation of oily-bitumen and solid-bitumen,[14]

or (*b*) *the separation of vitrain, clarain, durain and fusain*, by specific gravity,[15] cannot yet be decided so certainly that a definite method can be recommended for general use.

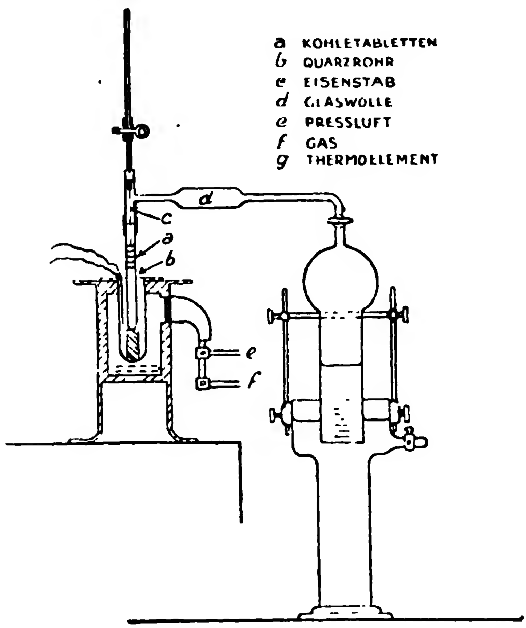

Fig. 9.—Geipert's apparatus for the determination of the calorific multiple of the gas.

(*a*) Coal tablets.
(*b*) Quartz tube.
(*c*) Iron rod.
(*d*) Glass wool.
(*e*) Compressed air.
(*f*) Gas.
(*g*) Thermo-element.

[13]Illingworth, *Gas- und Wasserfach*, 1923, p. 225;
Wheeler, *J. Chem. Soc.*, April, 1927;
Barash, *Fuel*, 1927, p. 532.
[14]Fischer and Gluud, *Ges. Abhandl. d. Kohle*, Vol. 3, p. 35;
Brennstoff-Chemie 1925, pp. 33 and 349.
[15]Dörflinger, *Kokereiausschuss d. Ver. dtsch. Eisenhüttenleute*, Bericht 26;
Kattwinkle, *Glückauf* 1928, Part 3.

In the case of gas coals, the determination of the *gas yield and of the calorific value of the gas*, in the apparatus described by Geipert[16] (Fig. 9), has proved entirely satisfactory. The coal is compressed into briquettes, which are perforated, strung on to a rod and introduced on this into a carbonising tube of fused silica heated to 1,100° C. The tar is retained by a filter of glass wool and the gas is collected in specially shaped measuring flasks. By careful adherence to the prescribed quantity of coal (10 gm.), the prescribed temperature (1,100° C.) and the prescribed dimensions of the heated tube, we were able to obtain an astonishingly complete agreement not only between observations by workers in different laboratories, but also with large scale results.

Thus, the method not only represents a valuable means for the assessment of the industrial value of gas coals on the basis of the yield of calories obtainable in the gas, but also a satisfactory basis for guarantees in connection with carbonising plant. Whereas previously a certain gas yield and calorific multiple were usually guaranteed on the assumption of the use of a "good gas coal" with definite water and ash contents, it will now be possible after a determination by Geipert's method to specify the "good gas coal" quantitatively in terms of the total calories contained in the gas. According to our results, the reproducibility is considerably better than that obtained by the much more troublesome manipulation required by Bauer's method[17] hitherto employed for the purpose, the value of which for the determination of the yield of by-products is in no way disputed.

In the case of coals for low-temperature carbonisation, more particularly lignites, the low-temperature distillation test is already standard. As, however, such a test also yields valuable information in the case of fuel for gas producers, it should be used much more generally than at present. Fischer and Schrader's aluminium carbonising retort[18] has proved exceedingly satisfactory in the Gas Institute. (Fig 10.)

The progressive development of the technology of gas producers and of pulverised fuel firing has had the result that a steadily increasing importance is attached to the determination of the *reactivity* of carbonised fuels in addition to that of the calorific value The attention of research workers has been directed with great interest to an explanation of this typical property of carbonised fuels, which has an essential influence on its behaviour in the fuel bed.[19]

Those interested in technology and in fuel analysis have, however, not yet realised sufficiently that the determination of reactivity is at least equal in importance to proximate analysis or the determination of calorific value, and that in many cases it is of even greater importance The bearing of the important results of Clement, Adams and Haskins,[20] for example, was completely overlooked for decades. The behaviour of coke in gas producers and in

[16] *Gas- und Wasserfach*, 1926, p. 861.
[17] *Journal für Gasbeleuchtung*, 1913, p. 389.
[18] *Ztschr. f. angew. Chem.*, 1920, p. 172.
Brennstoff-Chemie, 1920, p. 87.
[19] *Kopper's-Mitteilungen* 1923, Part 2.
Chimie et Industrie 1923, Vol. 8, No. 1;
Fischer, *Brennstoff-Chemie* 1923, p. 33,
Häusser and Bestehorn, *Ges. Unters. üb. d. Verbrennlichkeit von Hüttenkoks*;
Agde and Schmitt, "*Red. Fähigkeit von Steinkohlenkoks*," Knapp-Halle;
Metzger and Pistor, "*Die Reaktionsfähigkeit des Kokses*," Knapp-Halle.
[20] *Bureau of Mines*, Bull. 7, 1911.

CARBONISATION RESULTS: GEIPERT'S METHOD.

		Laboratory Experiments.						Plant Experiments.					
		Fuel laboratory of the Gas Institute.			Dr. Geipert's laboratory.			Horizontal retorts; experimental gas works at Karlsruhe.			Guarantee test; Düsseldorf coke ovens.		
Variety of coal.	Origin.	Gas in cu metres at 0°C. and 760 mm	Calorific value in Kg. calories per cu. metre at 0°C. and 760 mm	Calorific multiple of gas per 100 Kg of pure coal.	Gas in cu metres at 0°C and 760 mm	Calorific value in Kg. calories per cu. metre at 0°C. and 760 mm	Calorific multiple of gas per 100 Kg of pure coal.	Gas in cu. metres at 0°C. and 760 mm.	Calorific value in Kg. calories per cu. metre at 0°C. and 760 mm.	Calorific multiple of gas per 100 Kg of pure coal	Gas in cu. metres at 0°C and 760 mm.	Calorific value in Kg. calories per cu metre at 0°C. and 760 mm.	Calorific multiple of gas per 100 Kg. of pure coal
Dahlbusch-Zollverein mixture (1 : 1)	Ruhr	34·6	5,500	1,904	34·5	5,500	1,898	34·4	5,500	1,892	36·1	5,285	1,909
Gleiwitz ...	Upper Silesia	34·8	5,510	1,920	34·9	5,520	1,925	36·4	5,430	1,976	—	—	—
Königin Luise ...	,,	(a) 34·9	5,372	1,875	35·2	5,180	1,825	37·2	5,230	1,878	—	—	—
		(b) 35·5	5,189	1,843	—	—	—	—	—	—	—	—	—
Bahnschacht ...	,,	(a) 35·3	5,272	1,860	32·5	5,180	1,825	37·2	4,943	1,835	—	—	—
		(b) 36·8	5,140	1,890	—	—	—	—	—	—	—	—	—
Graf Bismarck ...	Ruhr	33·2	5,784	1,920	—	—	—	36·4	5,365	1,955	—	—	—

(a) = Observer 1.
(b) = Observer 2.

water-gas producers, the tendency to burn back on a travelling grate, the length of the pulverised coal flame and finally, for example, the right choice of the firing arrangements in central heating boilers—whether top-firing or bottom-firing—are dependent on the reactivity of the coke.[21] When we commenced to concern ourselves with this property and with its numerical determination, in the Gas Institute, we first proposed a method which depended on the reactivity with oxygen, and used the ignition point as a characteristic.[22]

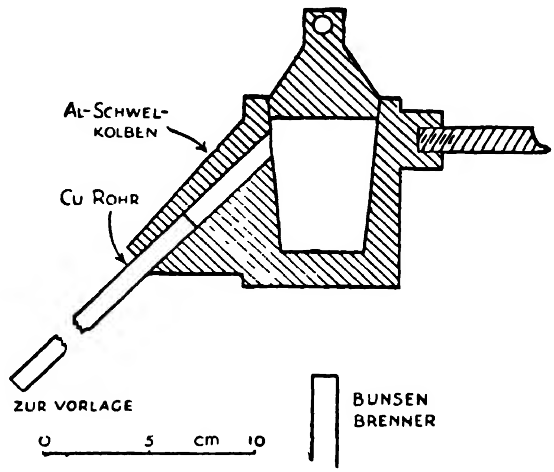

Fig. 10.—Fischer's low temperature retort.

Al-Schwelkolben = Aluminium retort
Cu Rohr = Copper tube
Zur Vorlage = To receiver
Bunsen Brenner = Bunsen burner

Subsequently, our work on the parallelism of ignition point and reactivity convinced us that reactivity towards CO_2 is equally easily determined experimentally, and at the same time allows this important property to be determined more exactly and more satisfactorily. In order to further the rapid standardisation of a method we decided to use the method proposed by Koppers,[23] and accepted by some consumers, according to which pure CO_2 is passed at 1,000° C., at a velocity of 30 c.c. per minute, through a tube of 5 to 6 mm. diameter, over 1 gm of coke (in grains of 0·5 to 1 mm. diameter) and the reactivity expressed in terms of the ratio of the CO_2 converted into CO, to the total CO_2 used:—

$$\frac{CO \times 100}{CO_2 + \frac{CO}{2}}$$

[21]Kreulen, *Brennstoff-Chemie* 1926, p. 54;
Korevaar, *Stahl und Eisen*, 1923, p. 431;
Follman, *Feuerungstechnik* 1927, p. 205.
[22]Bunte and Kölmel, *Gas- und Wasserfach*, 1922, p. 593.
Burte, Fitz and Ratzel, *Gas- und Wasserfach*, 1926, pp. 192 and 217.
[23]*Ztschr. d. V. D. I.*, 1925, p. 531.

By this method the determination may be carried out in about 2 hours. (Fig. 11.)

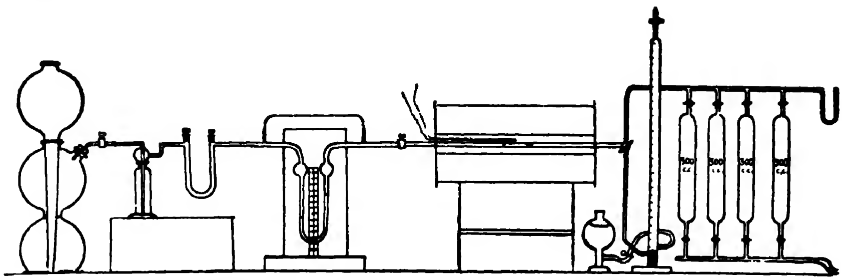

Fig. 11.—Apparatus for the determination of the reactivity of coke.

According to the experiments so far carried out by us the reactivities are shown by values approximately as follows:—

Wood charcoal	from	135	to	145
Lignite coke	,,	180	"	190
Semi-coke	,,	125	"	130
Gas coke (retort coke)	,,	80	,,	115
Gas coke (chamber coke)	,,	60	,,	90
Metallurgical coke	,,	30	,,	80

A complete conversion into CO would naturally give a figure of 200.

We consider that an object of the World Power Conference should be to initiate an interchange of views on the extension of methods of coal analysis, and for this reason we have described our experiences in order to stimulate such a discussion. More particularly, however, we consider it necessary that knowledge as to the progress of modern fuel analysis and as to the desirability and necessity for extending the present analytical scheme should be spread among wider circles of fuel consumers.

LES PROGRÈS DANS L'INDUSTRIE DES FOURS À COKE

(THE DEVELOPMENT OF THE COKING INDUSTRY)

FRENCH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

E. LANGROGNE

*Paper No. H*15

CONTENTS

RÉSUMÉ

On peut distinguer trois industries ayant pour objet la distillation de la houille:—

La première fabrique le coke métallurgique et utilise les fours à coke.

La seconde, l'industrie du gaz d'éclairage, emploie des appareils très variables: fours à cornues, fours à chambres, fours continus.

La troisième, encore dans l'enfance mais qui aura peut-être un jour un grand développement, est la distillation à basse température.

Nous avons, dans ce qui suit, l'intention de parler seulement de la fabrication du coke métallurgique, les deux autres industries devant faire l'objet de communications spéciales. Nous considérerons toutefois les points de rapprochement entre l'industrie des fours à coke et la fabrication du gaz d'éclairage.

Ces industries qui étaient souvent considérées comme séparées par un large fossé, bien qu'il s'agisse en définitive de faire subir un traitement identique à la même matière, se sont depuis quelque temps considérablement rapprochées. Ce phénomène est dû à une évolution des deux industries, comme nous le verrons plus loin, et à une modification dans les exigences des consommateurs.

D'ailleurs, les transformations survenues dans l'industrie de la carbonisation de la houille ont surgi sous la pression des circonstances. Avant la guerre, cette industrie était une opération secondaire des industries houillère et métallurgique, sans influence déterminante sur leur prospérité. Aujourd'hui, il n'en est plus de même, car le prix de revient du coke et de ses sous-produits a pris une importance considérable. Il faut donc comprimer les dépenses dans tous les domaines: achat de la houille, fabrication du coke, vente aussi rémunératrice que possible des sous-produits.

Dans ces trois ordres d'idées, des progrès notables ont été faits que nous allons passer en revue dans l'ordre suivant:—

Extension de la gamme des charbons cokéfiables.

Modernisation des usines à coke.

Rapprochement entre les usines à gaz et les cokeries.

EXTENSION DE LA GAMME DES CHARBONS COKÉFIABLES

Cette question intéresse spécialement les pays comme la France où les charbons gras à coke proprement dits sont relativement rares, alors que les besoins en coke métallurgique suffisamment dur et cohérent pour être passé dans les grands fours modernes se sont considérablement accrus avec la reprise de la Lorraine où se trouvent d'immenses et très modernes usines métallurgiques. Ces usines, construites par les industriels allemands propriétaires de mines en Westphalie s'approvisionnaient uniquement en coke de Ruhr. En même temps que les Français devenaient propriétaires de ces usines, la France acquerrait la propriété des mines de la Sarre.

Or, les Mines de la Sarre ne disposent pas de véritables charbons à coke et le coke fabriqué dans la région ne pouvait être utilisé que dans les petits hauts-fourneaux locaux.

La France avait tout intérêt à chercher à utiliser ces mines, proches de la Lorraine, pour les approvisionnements de ses grands hauts-fourneaux.

Des recherches furent entreprises de différents côtés à cet effet et elles ont abouti à l'application d'un procédé qui a reçu maintenant une consécration industrielle. Il est basé simplement sur l'amélioration d'un procédé déjà utilisé autrefois, consistant à mélanger les charbons très chargés en matières volatiles avec des charbons maigres et à pratiquer la cokéfaction dans des conditions un peu particulières.

(*a*) *Composition des Mélanges.*—La nature des charbons composant le mélange dépend essentiellement des facilités d'approvisionnement de la cokerie et, par suite, de sa position géographique.

Si le mélange des charbons à gaz et des charbons maigres donne, dans certaines conditions, un coke utilisable dans les grands hauts-fourneaux, il est préférable d'utiliser le mélange à trois composants:—

Charbons très chargés en matières volatiles,
Charbons maigres,
Charbons à coke,

qui ne supprime pas complètement la consommation de charbons à coke, mais la réduit dans une proportion considérable.

La réalisation industrielle du procédé de mélange des charbons n'est pas aussi simple qu'il peut le paraître d'après l'exposé que nous venons d'en faire. La préparation des mélanges demande, en effet, des précautions très spéciales pour permettre d'obtenir un coke de qualité convenable. Il faut que le dosage des charbons soit précis et régulier. Pour cela, le charbon doit être broyé, puis dosé au moyen de distributeurs précis, mélangé avec des vis malaxeuses et enfin pulvérisé dans de puissants désintégrateurs.

Ces diverses opérations nécessitent des appareils plus perfectionnés que ceux utilisés par les cokeries d'avant-guerre. En particulier, les appareils doseurs ont dû être établis spécialement, et la part faite aux manutentions dans les cokeries lorraines est au moins égale à celle des fours proprement dits.

La proportion des divers charbons à employer demande une étude expérimentale assez délicate. Les essais de laboratoire ne donnent en pratique que des résultats trop approximatifs. On est amené dans les cokeries qui varient souvent leurs mélanges de charbons à utiliser des installations d'essais permettant d'étudier expérimentalement sur quelques fours les mélanges de charbon envisagés.

(*b*) *Cuisson des Mélanges.*—L'expérience a montré que la qualité du coke obtenu avec des mélanges de charbons très gras et de charbons maigres augmentait par une cuisson rapide et une compression du gâteau de charbon.

Le pilonnage résoud une partie du problème, mais il comporte de multiples inconvénients parmi lesquels on peut citer la complication des machines et la limitation de la dimension des fours.

On a essayé de le supprimer en augmentant la hauteur des fours et, par suite, la pression intérieure du gâteau de charbon.

Quant à la cuisson rapide, elle a conduit à adopter des fours relativement étroits en briques de silice.

Ces desiderata ont été satisfaits par l'adoption des grands fours modernes, dont l'étude avait été poursuivie pour d'autres raisons et sur lesquels nous reviendrons plus loin.

La première tentative de ce genre a été faite à l'usine de Thionville

en 1923. Les résultats obtenus ont été assez satisfaisants pour que toutes les batteries en construction dans l'Est de la France soient du même type, c'est-à-dire soient composées de fours de grande capacité, doublés d'une manutention de charbon très puissante et très complète. La Sarre elle-même est en voie d'adopter des fours analogues.

A vrai dire, le coke obtenu n'est pas toujours de qualité égale à celle des cokes réputés du nord de la France ou de la Ruhr. Cependant, il permet d'alimenter sans aucune difficulté les plus grands hauts-fourneaux, surtout s'ils dépendent de la même direction que la cokerie. Il n'en va pas tout à fait de même pour une cokerie qui aurait de multiples clients, aux goûts desquels elle doit se plier.

Le procédé des mélanges, tel que nous l'avons décrit, est actuellement celui qui est adopté dans la plupart des usines lorraines. Il existe une variante très intéressante de ce procédé qui a été étudiée et mise au point industriellement aux Mines de la Sarre: le procédé au charbon semi-distillé.

Ce procédé est bien une variante du procédé des mélanges puisqu'il utilise le charbon gras de la Sarre en mélange avec du charbon maigre et que les conditions d'emploi de ce mélange sont identiques à celles des mélanges de charbon dont nous avons parlé plus haut.

Ce procédé est cependant très original du fait que le charbon maigre employé en mélange avec le charbon gras est fourni pour la distillation à basse température de ce même charbon gras, ou d'un charbon flambant analogue et fourni également par les Mines de la Sarre.

La distillation à basse température dont l'étude est poursuivie activement dans le monde entier, présente de grosses difficultés d'organisation. Les Mines de la Sarre sont cependant arrivées à mettre au point une installation industrielle capable de produire des semi-cokes bien définis à partir des charbons gras (Fettkohle) et des charbons flambants (Flammkohle) sarrois. Cette distillation produit, en abondance, du goudron et du benzol. Elle produit, en outre, des semi-cokes ou charbons maigres artificiels qui peuvent remplacer avantageusement, dans les mélanges destinés à la cokéfaction, les charbons maigres naturels.

Les Mines de la Sarre fabriquent ainsi sous le nom de coke spécial, un coke de très bonne qualité en utilisant uniquement les charbons du bassin de la Sarre.

Modernisation des Cokeries

Si on a pu facilement étendre la gamme des charbons cokéfiables le succès est dû en grande partie au fait que des améliorations très

sérieuses avaient été également apportées au mode de cokéfaction.

L'industrie métallurgique en effet doit chercher constamment à abaisser ses prix de revient par suite de l'activité de la concurrence dans cette branche. Il est certain que l'usine métallurgique qui dispose de coke métallurgique fabriqué à bon compte par ses hauts-fourneaux, est dans une situation tout à fait privilégiée sur l'usine qui est obligée de s'approvisionner dans le commerce.

On a donc été amené à adopter pour les installations nouvelles les progrès les plus récents de la technique permettant d'obtenir les prix de revient les plus bas.

A cet effet, on a fait baisser à la fois les frais de premier établissement et les frais d'exploitation en employant les fours en briques de silice.

Ces fours ont actuellement comme dimensions courantes 4 m. à 4 m. 50 de hauteur, 40 cm. de largeur et 12 à 13 m. de longueur. Ils permettent de traiter en 12 à 13 heures, une quantité de charbon de 14 tonnes environ, soit près de 25 tonnes par jour. Nous sommes loin des fours à coke d'avant-guerre qui ne pouvaient traiter que des chargements de 8 tonnes en 24 heures. Ce résultat a été atteint en accroissant la hauteur et la longueur des chambres et en réduisant leur largeur.[1] En outre, l'emploi de la brique de silice, beaucoup plus réfractaire que la chamotte employée autrefois, permet d'obtenir sans danger pour les fours des températures de cuisson beaucoup plus élevées.

Les frais de premier établissement et les frais d'exploitation sont considérablement réduits en même temps que les caractéristiques convenant le mieux à la cuisson des mélanges de charbon sont respectées: étroitesse et hauteur des chambres, température élevée de chauffage.

On conçoit donc le succès qu'ont eu partout de telles installations qui satisfaisaient en même temps aux divers aspects du problème.

Ces résultats, pour intéressants qu'ils soient, seront probablement dépassés avant peu. Actuellement, on construit des fours de 6 m. de hauteur et il est possible que les fours de l'avenir aient des dimensions encore plus élevées.

Les constructeurs de ces fours modernes ont rencontré des difficultés et dû engager des dépenses considérables pour atteindre les résultats actuels. Certains ont dû trouver des types de fours entièrement nouveaux, créer des batteries d'essais, concevoir des machines de service à puissance assortie à celle de leurs fours

[1]La largeur des fours ramenée par certains constructeurs à 35 centimètres est revenue maintenant à 42-45 centimètres.

et résoudre les difficultés nombreuses que présente toujours un changement aussi total des plans primitifs.

L'adoption de la brique de silice dont la fabrication et l'emploi sont particulièrement délicats, a obligé à créer des usines et une technique nouvelles. Enfin, l'obligation de réduire la main-d'œuvre a contraint le constructeur à trouver des perfectionnements multiples: régulateurs de pression de gaz, de tirage des cheminées d'aspiration des gaz de distillation, inverseur automatique, dégraphitage automatique, appareils de contrôle enregistreurs permettant de suivre les variations de tous les facteurs dont dépend la marche régulière des fours: pressions, températures, pouvoir calorifique, analyse des produits de combustion, débit du gaz, etc. Tous ces appareils sont maintenant groupés dans une salle unique, par batterie ou par groupe de batteries et permettent au surveillant ou au régleur des fours de savoir à chaque instant la marche exacte de leurs appareils. On arrive ainsi à une régularité de fonctionnement telle que les défournements peuvent être faits à heure fixe, suivant un barème immuable. Le rendement du personnel et des appareils est ainsi porté au maximum. Un fonctionnement aussi rigoureux ne peut être obtenu que si tous les appareils mécaniques qui desservent les batteries et qui remplacent les manœuvres d'autrefois, sont d'une solidité à toute épreuve et d'un fonctionnement absolument sûr. On arrive d'ailleurs pratiquement à des résultats qui surprennent, et nous connaissons une usine où une série de machines de service suffit à assurer 200 défournements par jour, ce qui ne laisse qu'une marge de temps insignifiante pour le graissage et l'entretien.

Les portes sans lutage dont l'adoption a été rendue nécessaire par la grande hauteur des fours, sont maintenant parfaitement au point et elles constituent un progrès immense sur les anciens systèmes à lutage à l'argile: réduction de la main-d'œuvre, étanchéité constante, propreté et commodité de manœuvre.

Les machines des cokeries actuelles ne ressemblent d'ailleurs pas aux machines d'avant-guerre. Le pilonnage est supprimé, les défourneuses à moteurs puissants et multiples supprimant les embrayages, sont manœuvrées électriquement avec rapidité et précision. Les nouvelles machines très larges et très dégagées permettent un accès facile à tous les points du mécanisme, et sont munies d'un système d'arrache-portes électriques installé de telle sorte qu'un seul machiniste, sans déplacer la machine, enlève la porte, défourne le saumon et remet la porte en place.

Les coal-cars, d'une taille proportionnée à la dimension des fours,

sont à manœuvre entièrement électrique et munis d'un système d'agitation permettant à un seul homme le chargement et la vidange du wagon.

Le guide-coke également électrique est en général monté avec l'arrache-porte de façon que le même homme puisse assurer la manœuvre des deux appareils.

Les grands fours s'accommodent mal des aires de défournement même de grande dimension. Partout, le coke-car se généralise grâce à sa robustesse et au gros avantage qu'il a de libérer immédiatement le four vidé, ce qui permet de le remplir de nouveau sans perte de temps. La tour d'extinction et le coke-wharf complètent l'installation d'extinction moderne qui, en dehors de l'économie de main-d'œuvre qu'elle procure, et de sa propreté, permet une réduction notable de la teneur en eau du coke. Il est vraisemblable que ce dernier système sera remplacé un jour prochain par les procédés d'extinction du coke à sec et de récupération des calories du coke rouge.

A côté de ces perfectionnements importants qui frappent même le profane, il faut faire une place pour les multiples perfectionnements de détail dont nous ne saurions donner ici une énumération complète et qui jouent leur rôle en réduisant le travail du personnel, en le rendant moins pénible, et enfin en supprimant la main-d'œuvre spécialisée.

Il est d'ailleurs intéressant de constater que ces perfectionnements ont souvent l'avantage d'accroître soit le rendement, soit la qualité des produits récupérés. Nous pouvons signaler parmi les nouveautés ayant fait leurs preuves: les colonnes montantes calorifugées ne graphitant pas ou du moins fort peu, l'arrosage intensif des barillets à l'eau ammoniacale améliorant la qualité du goudron, l'aspiration des gaz au chargement des fours fonctionnant à la vapeur, les armatures puissantes des batteries et leurs plaques de protection supprimant le travail de rejointoiement des façades des anciennes batteries, etc.

La difficulté de réalisation des grands fours a obligé à étudier de très près la technique du chauffage des fours. De nouveaux progrès ont été réalisés dans la récupération des chaleurs perdues et dans l'utilisation des calories du gaz de chauffage. Actuellement, le chauffage des fours ne nécessite pas plus de 40 pour cent de gaz produit par les fours, alors qu'avant la guerre cette proportion était souvent renversée.

Ces installations modernes nécessitent pour leur conduite des techniciens de plus en plus qualifiés, non seulement par suite de

l'importance des problèmes qui se posent, mais surtout par suite de la valeur des installations et des capitaux engagés.

La conduite des cokeries qui était autrefois purement empirique, devient sous la poussée du progrès justiciable des méthodes de contrôle les plus scientifiques.

Nous avons signalé l'importance des appareils de contrôle dans la conduite des fours, nous en reparlerons à propos des usines à sous-produits. Nous voulons seulement signaler ici un progrès bien simple, mais dont l'importance ne saurait échapper: la pesée exacte du charbon et du coke qui est la base même des calculs de rendement de l'usine et qui fut négligée pendent si longtemps.

Actuellement, les fours modernes sont munis d'appareils qui permettent de se rendre compte, presque four par four, des quantités de charbon traitées et des quantités de coke obtenues.

Nous avons examiné jusqu'ici la question des cokeries métallurgiques et gazières au seul point de vue des fours à coke. Des progrès non moins intéressants ont été réalisés dans les installations à récupération de sous-produits.

Les usines à sulfate dérivent presque toutes du procédé semi-direct; elles ont actuellement atteint un degré de perfectionnement tel qu'on voit, assez difficilement, les progrès supplémentaires qu'elles pourraient réaliser. Cependant, on cherche de divers côtés la possibilité de se passer de l'acide sulfurique pour la fabrication du sulfate d'ammoniaque, en utilisant pour cela le soufre contenu dans le gaz, ou le sulfate de chaux. Ces procédés ne se généralisent pas encore et sont plutôt au stade d'expériences, mais nul doute qu'ils n'aient l'avenir pour eux.

Les usines à benzol ont été depuis la guerre l'objet de perfectionnements importants. Le procédé classique de lavage à l'huile permet actuellement d'extraire la presque totalité du benzol contenu dans le gaz; les installations les plus modernes laissent moins de 1 gr. de benzol par m^3 et le benzol produit est lui-même d'une plus grande pureté. Ce benzol se lave sans subir de rectification supplémentaire. Enfin, la fabrication des produits purs, grâce aux appareils continus, se généralise et seul le manque de débouchés limite cette fabrication.

Les Cokeries et le Gaz d'Éclairage

Les progrès réalisés par l'industrie des fours à coke devaient intéresser l'industrie du gaz qui cherchait par des voies différentes l'abaissement de son prix de revient. Depuis longtemps déjà, certaines villes situées au voisinage des cokeries trouvaient intérêt à

acheter et à distribuer du gaz de fours à coke plutôt qu'à installer et entretenir des usines à gaz. On avait pu se rendre compte ainsi que le gaz de fours à coke était susceptible de rendre les mêmes services que le gaz produit dans les usines à gaz ordinaires.

Cependant, entre cette constatation et l'adoption de fours à coke pour la fabrication du gaz d'éclairage, il y avait à résoudre des difficultés considérables. On peut dire qu'actuellement la plupart des difficultés sont résolues et que le développement des cokeries gazières est certain.

Les difficultés auxquelles nous faisons allusion sont à la fois d'ordre technique et commercial.

L'usine à gaz est avant tout destinée à produire du gaz d'éclairage. Tout le reste de sa fabrication, coke, ammoniaque, goudron, benzol, peut être considéré comme sous-produits. Pour qu'un four à coke donne satisfaction, il faut donc qu'il fournisse avant tout et régulièrement un gaz de bonne qualité.

Les progrès réalisés dans l'industrie du coke ont résolu en grande partie cette difficulté. Les fours modernes, remarquablement étanches, munis d'appareils perfectionnés, donnent sans difficulté un gaz dont le pouvoir calorifique dépasse largement 4.500 calories. Or, la tendance actuelle dans tous les pays est de réduire le chiffre contractuel exigé du concessionnaire pour le pouvoir calorifique du gaz. On peut donc dire qu'à ce point de vue les fours à coke sont susceptibles de donner toute satisfaction. Ce résultat est très remarquable si on considère que les fours d'avant-guerre n'arrivaient à produire un tel gaz que par l'adoption de la sélection du gaz, ce qui entraînait le doublement de tous les appareils destinés à la récolte des sous-produits.

On doit cependant faire remarquer que le pouvoir calorifique du gaz dépend beaucoup des charbons employés; aussi la possibilité d'employer des charbons à forte teneur en matières volatiles pour la fabrication du coke métallurgique a, au point de vue gazier, une importance primordiale.

L'usine à gaz doit produire la plus grande quantité de gaz possible par tonne de charbon et, par conséquent, la plus petite quantité de coke possible. On a fait, pendant longtemps, aux fours à coke, le reproche de produire par mètre cube de gaz beaucoup plus de coke que les usines à gaz. Cette objection n'a de valeur qu'autant que la cokerie gazière est située dans une région où l'écoulement du coke métallurgique est difficile. Elle n'en était pas moins très sérieuse jusqu'à l'époque où le succès des fours à coke compound, chauffés au gaz de gazogène a résolu le problème. Le four à coke

actuel, chauffé comme les fours d'usines à gaz avec du gaz pauvre, produit, avec un charbon donné, une quantité de gaz égale à celle produite par les meilleurs fours à gaz.

Un problème des plus importants pour les cokeries gazières est celui de la qualité du coke fabriqué, car il dépend avant tout des débouchés locaux. Le coke des cokeries gazières peut, en effet, être vendu comme coke de hauts-fourneaux, coke de fonderie ou coke concassé pour usage domestique. Souvent d'ailleurs, la cokerie gazière sera amenée à fabriquer ces trois catégories simultanément. Or, ces diverses espèces de coke exigent un mode de fabrication différent et parfois contradictoire avec le bon rendement en gaz. Dans chaque catégorie même, les exigences des clients sont extrêmement variables. Il faut non seulement des mélanges et des charbons différents, mais une technique et des installations différentes. On peut, en particulier, être amené à employer pour la fabrication du coke de fonderie le pilonnage du charbon qui donne au coke un meilleur aspect et accroît sa dureté. Au contraire, la cokerie gazière ayant un débouché assuré vers le chauffage central n'aura pas à se préoccuper de cette question.

Les différences des conditions dans lesquelles doivent être construites les cokeries gazières ont eu pour résultat de faire adopter des types très variables dans les cokeries gazières ne dépendant pas directement d'une mine ou d'une usine métallurgique, mais il est probable que, dans l'avenir, à mesure que l'éducation du client se fera et qu'il s'accoutumera au coke de dimensions restreintes, l'évolution se fera partout dans le même sens que celui des cokeries métallurgiques, c'est-à-dire vers le four de grande capacité à cuisson rapide.

Deux cokeries purement gazières ont adopté, en France, ce type de four, la cokerie de Strasbourg et celle de Gennevilliers (Cokeries de la Seine).

Nous avons vu que l'intérêt provoqué par les fours compound dans les milieux gaziers était dû à la possibilité de chauffer ces fours au gaz pauvre, ce qui rend disponible la totalité du gaz riche. Il est donc intéressant de noter les progrès qu'ont faits les appareils producteurs de gaz pauvre. Les fours à gaz et les fours métallurgiques emploient souvent le gazogène accolé aux fours, ce qui offre l'avantage d'utiliser la chaleur sensible du gaz. Dans le cas de fours à coke, cette disposition n'est pas possible, car le gaz doit être employé froid et surtout dépoussiéré. On est donc obligé d'utiliser des gazogènes indépendants à hauts rendements.

Les gazogènes actuellement employés dans les cokeries dérivent

du type à décrassage automatique et à allure rapide. Les revêtements réfractaires ont dû être abandonnés par suite de l'action destructive du coke et des cendres, ainsi que de la haute température de marche. On emploie souvent le water-jacket formant chaudière, de façon à éviter toute condensation sur les tôles et, par conséquent, corrosion intérieure. Ce dispositif a, en outre, l'avantage de permettre la récupération d'une quantité notable de chaleur sous forme de vapeur utilisable pour le soufflage des gazogènes et les turbines pour l'entraînement des machines de service des appareils, ventilateurs, etc.

Rien n'a été négligé par les constructeurs pour abaisser le prix de revient du gaz pauvre et réduire la main-d'œuvre nécessaire. A ce point de vue, certaines installations entièrement automatiques, fonctionnent avec un ou deux hommes par poste et pour des puissances de gazéification de 40 à 60 tonnes de coke par 24 heures. Ces progrès des installations de gazogènes ont une importance tout à fait sérieuse pour le développement des cokeries gazières.

Il ne nous appartient pas d'aborder ici, dans le même ordre d'idées, le problème du transport du gaz riche à longue distance, actuellement à l'étude et même en usage dans certains pays; signalons seulement en passant que sont fondés sur lui, notamment en Allemagne, d'immenses espoirs.

Au total, les progrès récemment introduits dans la carbonisation à haute température peuvent se résumer comme suit:—

(1) Extension de la gamme des charbons susceptibles d'être traités en fours à coke, grâce aux améliorations apportées dans la composition des mélanges de charbons et à l'augmentation de la rapidité de cuisson et de la hauteur des fours.

(2) Diminution des frais d'établissement et d'exploitation des fours à coke par la mise en service d'unités puissantes étudiées soigneusement dans tous leurs détails.

(3) Développement de la fourniture de gaz d'éclairage par les cokeries, grâce aux meilleures conditions d'exploitation qui permettent d'obtenir un pouvoir calorifique comparable à celui des usines à gaz, au chauffage des fours à coke par le gaz de gazogènes, et au développement de la consommation du coke métallurgique, notamment dans le chauffage central des immeubles et appartements.

RÉSUMÉ

The industries which specialise in the carbonisation of coal can be classified into three sections, namely:—

1. The coking industry, for the production of metallurgical coke.

2. The gas industry, utilising carbonising plants of various designs.
3. Low-temperature carbonisation, which is practically through the experimental stage and is being developed towards an economic solution.

This paper deals only with the production of coke suitable for metallurgical purposes; the similarities between the two first named industries, however, are discussed. The author explains the practicability of utilising non-coking coals for the production of metallurgical coke by suitably blending lean coals with high volatile and other coking coals. It has been found that the quality of the coke produced from blended coals can be further improved by compression of the charge, high carbonising temperatures and reduction of the coking time, the latter being obtained by the adoption of narrow chambers built in silica material. Although the quality of the coke produced from blended Saar coals is not comparable to that obtained from the mines of the Ruhr or of northern France, it can be used for blast furnaces without any difficulty. Blending of coals of high volatile content with semi-coke obtained by carbonisation of the same coal at low temperatures is being carried out successfully in the Saar district on an industrial scale. The fact that a greater number of varieties of coals can now be utilised for the production of coke is due in a great measure to the development in coke-oven design. The present usual dimensions of the ovens are approximately as follows:—

height, 4 to 4·5 m.
width, 40 cm. and
length, 12 to 13 m.,

carbonising 14 tons in 12 to 13 hours. Improvements have been made with regard to the charging, handling and conveying of coal and coke, as well as in the method of heating the ovens and in fuel economy generally. The overall costs of production can be reduced by the installation of large units. Sulphate of ammonia recovery is now generally carried out by the semi-direct method. Further developments will probably lead to the utilisation of the sulphur contained in the crude gas in place of the sulphuric acid used at present. Methods of benzol recovery have been improved to a high degree of efficiency. In plants of modern design the benzol content in the wasted gas does not exceed 1 gramme per cu. m. of gas.

The gas industry has taken a great interest in the development of the coking industry. The possibility of co-ordination between the two depends on the capability of the coke-oven plants to produce a gas which in quality and constancy of calorific value and composition, is equivalent to that obtained from gasworks. Further economies can be realised by heating the ovens with producer gas from central producers, which utilise low grade coke, thus making available all the coke-oven gas for domestic and industrial purposes, jointly with the gas supplied by the gasworks.

LA GAZÉIFICATION DES COMBUSTIBLES AU MOYEN DU GAZOGÈNE À FUSION DES CENDRES

(THE GASIFICATION OF FUELS BY LIQUID SLAG PRODUCERS)

FRENCH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

A. DESSEMOND

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CONTENTS

Les perturbations profondes apportées par la guerre dans les conditions générales de l'industrie et notamment le renchérissement mondial des prix de la main-d'œuvre et des transports déterminent à l'heure actuelle une évolution qui est susceptible de s'accentuer par la suite dans le mode d'utilisation des calories.

Partout on cherche à réaliser l'utilisation la plus complète des combustibles dans les conditions d'emploi les plus commodes, en supprimant en particulier, quand cela se peut, l'emploi de toute main-d'œuvre spécialisée.

Le phénomène est déjà bien net dans les agglomérations urbaines où des applications nombreuses de chauffages centraux collectifs ont été réalisées ou sont en cours d'étude, et où le gaz et l'électricité tendent à remplacer la houille pour assurer le chauffage individuel quand il est conservé.

Il en est de même dans l'industrie où le développement de nouveaux modes de combustion a été des plus remarquables et où l'on s'est efforcé tout d'abord d'utiliser les calories parfois totalement perdues autrefois, ou partiellement et incomplètement employées par le service des récupérateurs ou des chaudières, et de rechercher comme

on l'a fait une valorisation plus complète et plus rémunératrice des calories contenues dans les gaz résiduels.

Mais les nécessités d'une concurrence de plus en plus vive, le développement des procédés de synthèse de l'ammoniaque et des carburants, les difficultés d'écoulement des combustibles crus ou des cokes, accentuées par la majoration des prix de transport, vont sans doute amener les mines et les usines à rechercher dans leur intérêt commun une rationalisation plus parfaite, c'est-à-dire une adaptation meilleure des qualités de charbon aux exigences des consommateurs et aussi une transformation radicale des conditions anciennes d'utilisation des combustibles.

L'utilisation des calories contenues dans les gaz des hauts-fourneaux est méthodique et complète depuis longtemps déjà.

Il n'en est pas de même encore pour le gaz de fours à coke. Jusqu'à ces dernières années une partie de ces gaz était utilisée dans les cokeries de mines pour le chauffage de ces fours eux-mêmes, tandis que les gaz en excès étaient brûlés sous les chaudières des cokeries ou des mines. Des essais d'utilisation des gaz de fours à coke pour l'éclairage des agglomérations urbaines ont été réalisés avec succès en France dès 1912. Ces essais sont en voie de généralisation, et l'on connaît les projets grandioses de l'A.G. Kohleverwertung en vue de l'alimentation de l'Allemagne par les cokeries de la Ruhr.

Toutefois dans la plupart des cokeries de mines, le chauffage des fours à coke restait encore assuré jusqu'à ces dernières années au moyen des gaz de fours en excès. La nécessité de libérer ces volumes importants de gaz doit entraîner dans l'avenir le chauffage des fours à coke au moyen de gaz pauvre comme cela se pratique dans les usines à gaz. D'importantes installations productrices de gaz pauvre devront être envisagées. On peut se demander à cette occasion si le gaz pauvre, produit ainsi en grande quantité, ne pourrait également être utilisé dans des installations industrielles venant se grouper au voisinage des mines ou des cokeries, et qui faute de trouver sur place les combustibles spéciaux susceptibles de fournir directement les hautes températures nécessitées par leurs fabrications, supportent des frais de transport élevés qui accroissent notablement leur prix de revient.

Dans cet ordre d'idées la possibilité d'utiliser pour la production de ce gaz des déchets de houille ou de coke, a déterminé la Société des Houillères de St-Etienne à se préoccuper du problème de la gazéification de ces déchets de houille et de coke en les enrichissant

lorsque cela est nécessaire par une addition de gaz de distillation de la houille. Elle a pu réaliser cette utilisation au moyen de gazogènes à fusion des cendres soufflés au vent chaud.

C'est dans ces conditions qu'elle assure d'une façon absolument continue depuis plusieurs années le chauffage des fours de la Société franco-belge de verrerie utilisant les procédés Libbey-Owens pour la fabrication mécanique du verre. Le chauffage de ces fours et de leurs accessoires, comporte, non seulement l'utilisation de gaz pauvre fourni par les gazogènes, mais celle de gaz riche fourni par une cokerie et celle du gaz mixte résultant d'un mélange dosé des deux gaz.

On peut voir là autre chose qu'un cas particulier et imaginer dans l'avenir une concentration d'usines utilisant de grandes quantités de calories autour de centres de production de ces calories sous forme de gaz riche ou de gaz pauvre sur le lieu même où ces gaz peuvent être fournis dans les conditions de prix de revient les meilleures.

Il nous a semblé, pour ces raisons, que la description de l'installation qu'a réalisée la Société des Houillères dans ce but pouvait présenter quelque intérêt.

Description générale de l'usine d'Achille

Matières premières. On consomme comme combustibles au gazogène un mélange de schistes ou déchets de triage et de coke cendreux, ne contenant pas une proportion excessive de menu, afin de maintenir dans la cuve une perméabilité suffisante. Ces matières sont additionnées de la quantité de castine nécessaire à la formation du laitier et en outre d'une certaine quantité de déchets de fonte plus ou moins imprégnés de laitier provenant de coulées précédentes, et jouant le rôle d'un volant de chaleur destiné à maintenir le profil du creuset.

Les compositions de ces diverses matières sont évidemment assez irrégulières; pour fixer les idées, nous admettrons dans les calculs qui suivront les analyses moyennes ci-après:

	Schistes.	Coke.
Humidité sur tout venant	3,0	15,0
Cendres sur sec	58,0	28,0
Matières volatiles	15,0	2,0

avec les compositions de cendres suivantes:

	Schistes.	Coke.
SiO_2	40,0	50,0
Al_2O_3	24,0	24,0
CaO	7,0	3,0
MgO	1,0	1,0
Fe_2O_3	28,0	22,0
Total	100,0	100,0

Manutention des matières premières. Les matières premières arrivant par wagons ou par bennes sont déchargées directement, soit dans de vastes cases en maçonnerie où elles sont stockées pour parer aux irrégularités des arrivages, soit dans 6 trémies en tole de 60 m³. de capacité chacune placées sous les voies.

La reprise se fait en principe directement sous les goulettes des accumulateurs et exceptionnellement par pelletage dans les silos au moyen de 4 wagonnets spéciaux en tôle de 1 m³; les charges successives sont pesées au passage sur 3 bascules.

La charge ainsi préparée est ensuite déversée latéralement par une trappe dans un skip incliné à 45°, actionné par moteur triphasé de 20 CV, avec ralentissement et arrêt automatiques en fin de course; la benne de 1 m³.5 est équilibrée par un contre-poids et son parcours total est de 32 m.

L'appareil de chargement au gueulard est constitué par une trémie formée à la partie supérieure par un chapeau soulevé par la benne avant son déversement et à la partie inférieure par un cône manœuvré à distance par l'air comprimé.

Les matières tombent ensuite dans un cylindre en tôle disposé à l'intérieur de la cuve du gazogène et assurent ainsi un bouchage complémentaire du gueulard.

Gazogènes. Les gazogènes sont constitués par une cuve cylindrique en tôle, garnie d'un revêtement réfractaire de 2 m.55 de diamètre extérieur et de 11 m.50 de hauteur totale; ils peuvent consommer chacun 100 T. à 150 T. de matières chargées par 24 heures, en produisant 180.000 m³. à 270.000 m³. de gaz à 1.200 calories environ.

Le vent chaud est distribué par un tore calorifugé muni de 8 tuyères à circulation d'eau de 80 mm de diamètre intérieur. La pression du vent aux tuyères mesurée en colonne d'eau est voisine de 1 m.20. La cuve est refroidie par ruissellement; les trous de coulée de la fonte et du laitier sont diamétralement opposés.

Soufflage et chauffage du vent. Chaque gazogène est alimenté par une soufflante centrifuge Rateau commandée directement par moteur triphasé, tournant à 2.900 tours par minute; le débit maximum est prévu pour 7.500 m^3. de vent à l'heure, sous une pression de refoulement de 3 mètres d'eau.

Le vent est ensuite réchauffé dans une batterie de 3 récupérateurs à tubes métalliques, à courants gazeux continus et à chauffage méthodique et accéléré système Philipon. Ces récupérateurs disposés en série ont un diamètre extérieur de 2 m. et une hauteur de 5 m.33. Grâce à la grande vitesse de circulation des gaz qui facilite les échanges de chaleur, l'encombrement de ces appareils, étant donné leur débit, est donc remarquablement réduit. On obtient ainsi une régularité parfaite de la température du vent avec des frais d'entretien très réduits.

Les brûleurs sont alimentés au gaz de gazogène et les fumées qui s'échappent à une température de 250 à 300° sont aspirées à travers le sécheur Huillard annexé à la cimenterie.

Un jeu de vannes et de tuyauteries permet de faire débiter indistinctement chacune des 2 soufflantes et chacune des batteries de réchauffeurs sur l'un ou l'autre des gazogènes.

Alimentation en eau. Enfin le service d'alimentation d'eau de la batterie complète des gazogènes est assuré par 3 pompes Sulzer (dont une de relai) refoulant à 20 m. de hauteur. Le circuit de l'eau de granulation est distinct du circuit de refroidissement. Toutes ces eaux sont récupérées après refroidissement dans un réfrigérant Hamon en ciment armé à 2 compartiments de 400 mètres cubes heure et d'une hauteur totale de 32 m. L'eau de granulation est décantée dans des bassins de 1.200 m^3. avant d'être réutilisée.

Coulée et manutention du laitier. Les coulées se font par éclusées toutes les 30 minutes; la fonte est coulée en sable ou en lingotières; le laitier granulé dans un fort courant d'eau est mis en tas sur parc au moyen d'un pont roulant de 20 m. de portée à benne preneuse, actionné par 3 moteurs de 3, 22 et 27 CV.

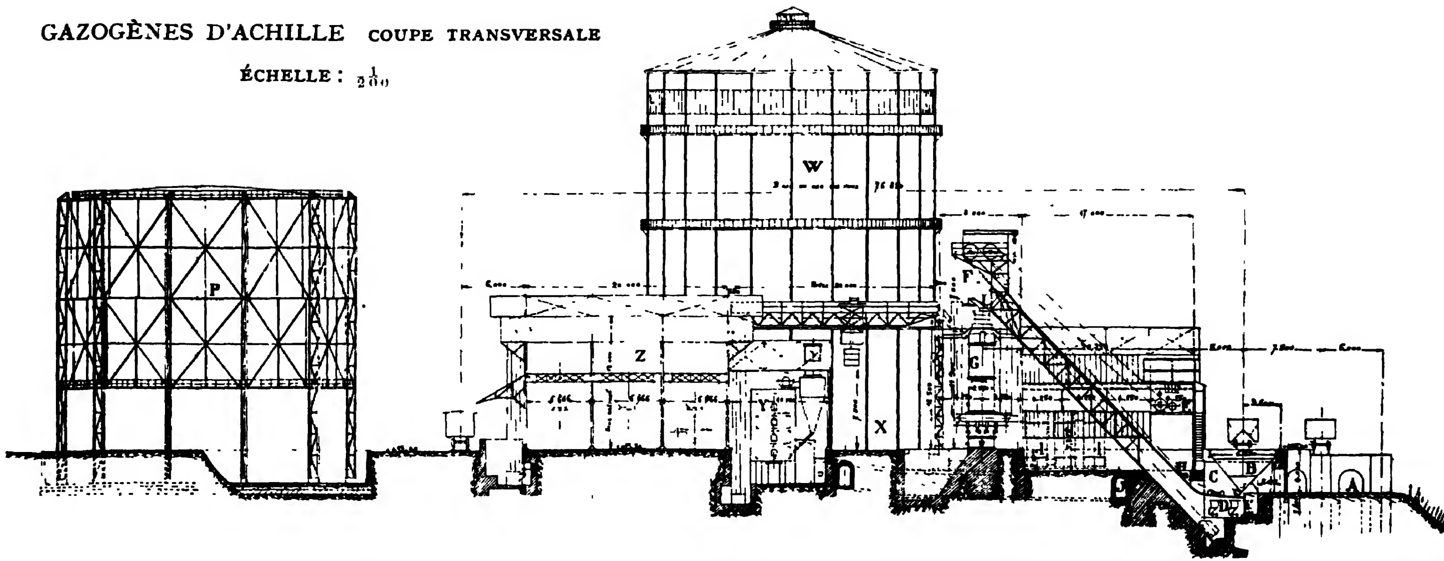
Abstraction faite des quantités repassées au gueulard, la production nette vendable de l'appareil ressort approximativement à 6 T. de fonte et 40 T. de laitier par 24 heures.

Produits obtenus. Le laitier obtenu a une composition variable qui se tient dans les limites suivantes:

SiO_2	30 à 35 %
Al_2O_3	20 à 25 %
CaO	40 à 44 %
MgO	0,5 à 1 %
FeO	0,5 à 0,8 %

GAZOGÈNES D'ACHILLE COUPE TRANSVERSALE

ÉCHELLE : $\frac{1}{200}$



LÉGENDE

A — Cases des matières premières.
B — Accumulateurs des matières premières 6 trémies de 58^{m3} chaque.
C — Fosses de chargement.
D — Bascules et wagonnets de chargement; 3 bascules et 4 wagonnets, capacité chaque 1^{m3}.
E — Cabines des treuils des Skips; puissance du treuil, 3.000 kg., vitesse de levage par minute 12^{m}, moteur 12 CV.
F — Skips, capacité chaque 1^{m3}5.
G — Gazogènes, 100T par 24 heures chacun.
I — Réchaufleurs; surface de chauffe pour 1 groupe de 3 réchaufleurs 135^{m2}68.
J — Carneau des fumées.
P — Gazomètre de 10.000^{m3} gaz pauvre; pression du gaz 1ère levée 160^{mm}, 2ème levée 220^{mm}.
W — Gazomètre de 20.000^{m3} gaz riche, pression du gaz 105^{mm}.
X — Parc à laitier.
Y — Four sécheur à laitier traitant par heure 12T de laitier à 10.12% d'eau et le ramenant à 1%.
Z — Cimenterie.

La fonte chaude, très siliceuse et peu sulfureuse constitue une bonne fonte d'addition pour moulages, contenant:

C	... ...	3,0 %
Mn	... ...	0,4 %
Si	... ...	9 à 11,0 %
P	... ...	0,5 %
S	... ...	0,030 %

Quant au gaz, il est caractérisé par une teneür élevée en CO et faible en CO_2:

CO_2	... ...	5,0 à 4,0 %
CO	... ...	28,0 à 31,0 %
H_2	... ...	3,0 à 5,0 %
CH_4	... ...	1,5 à 2,5 %
Az_2	... ...	55,0 à 60,0 %
p.c. inf.	... ...	1.150 à 1.200 c.

Epuration du gaz. En sortant du gueulard, le gaz traverse d'abord un cyclone de 3 m.20 de diamètre où se déposent les poussières les plus lourdes, puis il parcourt une conduite en V, munie de sacs à poussières.

Il traverse ensuite 2 scrubbers en série (un deuxième groupe est en relai) de 4 m. 50 de diamètre et de 13 m.30 de hauteur, munis d'injecteurs à pulvérisation d'eau et aboutit enfin à un désintégrateur Theisen où l'épuration s'achève au titre de 0 gr. 02 par m³. Momentanément cet appareil est également utilisé comme surpresseur mélangeur en vue d'emmagasiner dans un gazomètre télescopique de 10.000 m³. le gaz mixte à 1.400 calories utilisé par la Société franco-belge de verrerie.

Ce ventilateur est actionné par un moteur triphasé à 3.000 volts, tournant à 738 tours par minute et susceptible de débiter 26.500 m³. de gaz à l'heure en lui communiquant une surpression de 15 à 18 cm d'eau. L'eau vésiculaire entraînée par le gaz est arrêtée par un séparateur à chicanes.

Une pompe Rateau spéciale alimente à la pression de 10 kg. l'injection des scrubbers et du Theisen.

Utilisation du gaz. Le gaz produit dans les gazogènes est utilisé au chauffage des fours à bassin de la Société franco-belge pour la fabrication mécanique du verre à vitres par les procédés Libbey-Owens dont l'usine est installée à proximité immédiate. Il y est conduit par une tuyauterie aérienne de 800 mm de diamètre avec joints de dilatation.

Au préalable toutefois, le gaz est enrichi par une petite addition de gaz de fours à coke pour porter son pouvoir calorifique à 1.300 calories, ce qui permet de réaliser une économie importante sur les

frais de construction et l'encombrement des chambres de récupération.

Ce mélange actuellement réalisé au désintégrateur Theisen, se fera pour la batterie en complet état de marche, au moyen d'un ventilateur centrifuge Rateau déjà installé et muni de clapets de réglage automatiques afin de maintenir une proportion déterminée entre les débits des 2 gaz, malgré les variations de production de la batterie. Le mélange obtenu dans ces conditions, dont le pouvoir calorifique peut prendre toutes les valeurs désirées, est alors refoulé dans un gazomètre télescopique à eau de 10.000 m^3.

En dehors du gaz de gazogène, la Société franco-belge de verrerie utilise directement pour ses fours de réchauffage et pour les opérations annexes de son industrie une certaine quantité de gaz riche de fours à coke qui lui est conduit par une canalisation spéciale.

Ce gaz riche provient des batteries de fours à coke de Méons et est amené à l'usine d'Achille par une canalisation souterraine de 1.650 m. de longueur en tubes Mannesmann soudés électriquement. Il est emmagasiné dans un gazomètre sec à piston mobile et à joint au goudron de 20.000 m^3. de capacité.

Cimenterie. La cimenterie d'Achille utilise du laitier sec qu'elle transforme en ciment par broyage, après mélange avec une proportion déterminée de chaux. L'installation actuelle ne comprend qu'un groupe de broyeurs, mais le bâtiment doit ultérieurement renfermer 3 groupes analogues avec trémies et appareils d'ensachage. Le sécheur actuel est prévu du reste pour alimenter seul les 3 broyeurs.

Séchage du laitier. Le laitier humide pris en tas par le pont à benne déjà mentionné est versé par une toile transporteuse dans un sécheur Huillard, dans lequel un jeu de râclettes assure la descente de plateau en plateau. Les fumées aspirées des réchauffeurs par un ventilateur de 25 CV, traversent le sécheur et déposent ensuite dans un cyclone les particules de laitier entraînées. Le sécheur est prévu pour un débit horaire de 10 à 12 T. de laitier à 12 pour cent d'humidité, qu'il ramène à une teneur en humidité de 0,5 pour cent environ.

Manutention des matières premières. Le laitier sec est remonté par un élévateur vertical à godets et tombe sur un séparateur magnétique à 2 rouleaux: il y abandonne les petits grains de fonte qu'il peut renfermer et est ensuite dirigé par un transporteur à tube tournant avec spires inférieures en fonte, vers une trémie d'emmagasinage de 75 m^3.

La chaux est vidée dans une trémie de 8 m^3. puis elle est conduite par un élévateur à godets et une vis transporteuse dans une autre trémie de 75 m^3.

Dosage. Le laitier est repris par un distributeur à secousses et la chaux par un distributeur à vis; ces matières tombent dans une trémie réceptrice de mélange qui alimente les broyeurs. Deux petits élévateurs auxiliaires permettent d'y ajouter des produits d'addition exactement dosés.

Le réglage du débit des distributeurs pour obtenir un ciment de composition déterminée se fait très simplement par des poulies extensibles et des excentriques réglables. Le mélange est dosé à 20 à 30 pour cent de chaux pour 80 à 70 de laitier.

Broyage. Le mélange de chaux et de laitier traverse successivement 2 tubes broyeurs de 1 m.65 de diamètre et de 5 m. de longueur, tournant à 28 tours par minute. Chaque tube est commandé au moyen de manchons d'accouplement élastiques et d'un train d'engrenages par un moteur triphasé de 350 CV à 160 tours par minute, sous 3.000 volts, avec compensateur de phase pour améliorer le facteur de puissance. Les 2 tubes sont indépendants; le passage du ciment de l'un à l'autre se fait par un manchon en fonte muni de bras releveurs: une garniture en feutre assure l'étanchéité du joint; les paliers des broyeurs sont refroidis par circulation d'eau.

Le tube préparateur, partagé en 2 compartiments par une cloison perforée, renferme des boulets d'acier de deux grosseurs différentes; le tube finisseur contient des cylpebs ou petits cylindres à section circulaire en acier spécial très dur.

Manutention du ciment. A la sortie des broyeurs le ciment est repris par un élévateur vertical à godets et conduit par une vis transporteuse à une trémie de 150 m^3.

Il est mis en sacs de 50 kilogs au moyen de 2 ensacheurs doubles automatiques, alimentés par 2 extracteurs à vis.

Ciment obtenu. L'installation actuelle permet de produire environ 60 tonnes de ciment par poste de 8 heures. Ce ciment donne des résistances comparables à celles des meilleurs ciments Portland.

Mesurée à l'aiguille de Vicat, la prise commence 2 heures environ après gâchage et se termine 4 à 5 heures plus tard. Le résidu sur tamis n°200 de 4.900 mailles au cm^2. qui mesure officiellement la finesse, est de 4 à 8 pour cent. L'analyse donne les chiffres suivants:

Perte au feu	4 à 5%
SiO_2	25 à 27%
Al_2O_3	16 à 18%
CaO	48 à 50%
MgO	traces

Les résultats d'essais obtenus sur des ciments Achille fabriqués couramment par l'usine, permettent de dresser le tableau suivant:

ESSAIS DU CIMENT ACHILLE.

	Essai à la traction.	Essai à la compression.
1° — en pâte pure.		
Début de la prise : 1 h.55		
Fin de la prise : 7 h.20		
Résistance à 1 jour	18 k.5	150 k.
„ à 2 jours	26 k.7	185 k.
„ à 4 jours	32 k.4	215 k.
„ à 7 jours	36 k.8	230 k.
„ à 28 jours	38 k.4	240 k.
2° — en mortier 1/3.		
Début de la prise : 1 h.55		
Fin de la prise : 7 h.20		
Résistance à 1 jour	11 k.4	112 k.
„ à 2 jours	12 k.1	123 k.
„ à 4 jours	15 k.8	139 k.
„ à 7 fours	20 k.3	151 k.
„ à 28 jours	26 k.1	181 k.

La facilité et l'économie de la fabrication du ciment font donc de celui-ci un sous-produit intéressant des combustibles pauvres de faible valeur marchande dont il permet de valoriser utilement le laitier.

RÉSUMÉ

There is a general effort towards a more effective utilisation of fuels and the elimination of skilled labour wherever this is possible. Central heating, gas and electricity, are superseding coal for domestic heating. In the industry, where the development of modern methods of combustion has been very remarkable, a serious effort has been made to recover efficiently the surplus heat, which formerly was either entirely wasted or only partially utilised in recuperators and boilers.

The methodical and successful use of blast-furnace gas has been accomplished for some years. Regarding coke-oven gas, the position is not yet so favourable, as until quite recently most of the coke-ovens were being heated with their own gas, the surplus being used for firing boilers.

After the successful tests carried out since 1912, the utilisation of coke-oven gas in France is being adopted on a larger scale. The gigantic scheme of the A.G. Kohlenverwertung to provide all Germany with coke-oven gas from

the Ruhr district is well known. The necessity of liberating these large quantities of gas for other purposes will call for the production of low-grade gas for heating the ovens, similar to gasworks practice.

The production of producer gas in bulk raises the question of its possible utilisation for industrial purposes in works situated in the vicinity of the coke-oven plant. The resultant saving in fuel costs would considerably reduce the price of manufacture. The Société des Houillères de St. Etienne has solved the problem of utilising low-grade fuels, such as coal and coke screenings, for the production of producer gas, by means of a liquid slag producer with hot blast. The glass furnaces of the Société Franco-Belge, for the mechanical production of glass by means of the Libbey-Ovens process, have been continuously heated for some years by means of coke-oven gas or by a mixture of the two.

These examples illustrate the advantage of concentrating industries, consuming large quantities of heat units near coke-oven plants, which could supply either rich or low grade gas under advantageous conditions. The fuel supplied to the slagging gas producer at the Usine d'Achille consists of a mixture of shale or screenings and coke-breeze, high in ash, but excluding an excessive amount of fines. In addition to this fuel, the charge contains the necessary amount of limestone for the formation of the slag, and a certain amount of scrap cast-iron.

A suitable mixing and handling plant secures the correct proportioning of the charge. The brick-lined producers are 2·55 m. outside diameter, 11·5 m. in height and have a capacity for dealing with 100 to 150 tons of material per twenty-four hours, producing 180,000 to 270,000 cu. m. of gas of 1,200 cal per cu. m. The air blast is supplied to the producer by eight water-cooled tuyeres with a pressure of 1·2 m. water gauge. The blast is pre-heated in metal recuperators, heated by producer gas. The combustion gases leaving the recuperators at a temperature of 250 to 300°C. are further utilised in the driers of the cement plant.

The metal is tapped at thirty minute intervals for ingots; the slag, granulated by water, is conveyed to the yard by a tray conveyor. After deduction of the material required for the charge, the amounts available for sale are approximately 60 tons of ingots and 40 tons of slag per twenty-four hours. The iron is high in silica with a low sulphur content. The producer gas has the following composition:—

CO_2	3·0 to 4·0%
CO	28·0 to 31·0%
H_2	3·0 to 5·0%
CH_4	1·5 to 2·5%
N_2	55·0 to 60·0%
Cal. value	1,150 to 1,200 cal./cu. m.

The gas is cleaned by means of cyclones, scrubbers, and finally by a Theissen washer, down to a dust content of 0·02 grams. per cu. m In the Theissen washer, the producer gas is enriched by coke-oven gas to 1,400 cal./cu. m. A main of 800 mm. diameter provided with expansion joints, conveys the gas

from the holder to the glassworks of the Société Franco-Belge. These works utilise at the same time a certain amount of coke-oven gas, supplied from the coke-oven plant at Méons.

In the cement plant, the granulated slag is dried by waste heat to a moisture content of about 0·5 per cent., and passes through a magnetic separator to a rotary ball-mill. The pulverised slag is mixed with calcined lime and a few other ingredients. The mixture, consisting of 20 to 30 per cent. of calcined lime and 80 to 70 per cent. of slag, passes then to the rotary ball-mills.

The results of tests given in the paper indicate that the quality of this cement is comparable to the best Portland cement, and represents a valuable by-product in the utilisation of low-grade fuels.

MÉTHODES MODERNES DE PRODUCTION ET D'UTILISATION DES AGGLOMÉRÉS DE HOUILLE ET DE LIGNITE

(MODERN METHODS FOR THE PRODUCTION AND UTILISATION OF COAL AND LIGNITE BRIQUETTES)

FRENCH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

CH. BERTHELOT

*Paper No. H*18

CONTENTS

Exposé

Au cours de ces derniers mois, certains ont pu croire que l'industrie des agglomérés de houille approchait de son déclin, à cause de la réduction du nombre de consommateurs. Ceci se justifie par les faits suivants:

Les marines marchandes et militaires consomment moins de briquettes depuis l'extension de la chauffe au mazout.

Les chemins de fer tendent, eux-mêmes, à diminuer leurs dépenses de briquettes en raison de l'électrification plus avancée de certains réseaux.

Des fines de houille utilisables, autrefois, à l'état aggloméré seulement, trouvent maintenant un écoulement facile dans les foyers aménagés au moyen soit de grilles spéciales, soit de brûleurs pour recevoir des charbons pulvérisés.

Chaque fois qu'une industrie se trouve menacée dans son existence, elle s'adapte, en se perfectionnant, aux circonstances nouvelles ou bien elle disparait. La technique de la préparation des agglomérés

a fait l'objet de progrès importants au cours de ces derniers mois et s'est ouvert de nouveaux débouchés. Ce sont les uns et les autres que nous allons étudier ici.

Nous subdiviserons cette étude comme suit:

(*a*) *Perfectionnements relatifs à la préparation des agglomérés*
- Séchage des fines
- Agent agglomérant
- Aménagement d'une centrale de préparation mécanique et de dosage du brai
- Mode d'alimentation des presses
- Forme rationnelle des boulets
- Appareil de chargement des boulets

(*b*) *Modes nouveaux d'utilisation des agglomérés*
- Données générales sur les anthracites artificiels résultant de la carbonisation de la houille et des lignites à basse et à haute température
- Examen de la méthode des Mines de Nœux et de celle d'Anthra
- Étude de la méthode de Pieters

(*c*) *Autoagglomération du lignite*

Nous allons examiner successivement ces diverses questions.

Perfectionnements Relatifs à la Préparation des Agglomérés

La fabrication des agglomérés comprend les phases suivantes: [1]

1° Séchage du charbon;
2° Broyage de l'agglomérant et du charbon;
3° Mélange du charbon avec la proportion voulue d'agglomérant (7 à 8 pour cent. du poids du charbon, en général)
4° Compression du mélange dans une presse qui donnera aux produits la forme voulue.

Les perfectionnements apportés aux diverses étapes de cette fabrication se présentent comme suit:

(*a*) *Séchage des fines.*—Sauf le cas, de plus en plus rare, où l'on fait usage de presses à moule ouvert (type Bourriez), on ramène à 2 pour cent la teneur en eau des fines lavées qui en contiennent, généralement, de 10 à 12 pour cent à leur sortie des tours d'égouttage. Le plus souvent, on dessèche le charbon dans des fours verticaux comprenant plusieurs soles superposées (Huilard et Mourgeon, Réol,

[1] Pour plus amples détails, nos lecteurs voudront bien se reporter à notre ouvrage:
Ch. Berthelot. Les Combustibles dans l'Industrie Moderne. Encyclopédie Guillet.—Baillières Editeurs à Paris. Année 1928.

Usines de la Chaléassière) que traversent directement les fumées issues d'un foyer latéral et convenablement diluées d'air pour éviter toute surchauffe, donc tous risques d'inflammation spontanée de la houille en traitement. Dans certains de ces fours, le charbon, amené au centre de la sole par un tube d'alimentation est distribué et retourné sur la sole au moyen de palettes radiales fixes. Un racloir fait tomber le charbon dans une vis transporteuse assurant l'alimentation soit de la sole située au-dessous, soit celle du malaxeur. Dans d'autres modèles de fours de ce genre, on dispose alternativement des soles fixes et mobiles. L'alimentation de ces dernières a lieu par le centre, de sorte que le charbon y prend une direction centrifuge tandis qu'elle est de sens centripète sur les soles fixes, grâce à un jeu de raclettes mobiles.

Depuis quelques années, on a mis en service (Mines Fiscales de l'État Néerlandais, à Heerlen) des fours séchoirs chauffés au charbon pulvérisé. Leur fonctionnement paraît excellent au point de vue séchage, mais il convient de porter à leur passif leur fort encombrement (spécialement en longueur), ainsi que leurs frais élevés de premier établissement et d'exploitation.

Plus récemment à Heinitz, à Langgerbruge et aux Charbonnages d'Orange-Nassau (Limbourg hollandais), on a installé des fours horizontaux où le chauffage est assuré par surface tandis que le charbon y est déplacé par des raclettes. Le rendement thermique de ce four serait meilleur que celui des fours verticaux à soles superposées, en raison de l'inutilité de diluer l'agent de chauffage avec de l'air. Il ne rentre plus, en effet, en contact avec le charbon, ce qui écarte, d'ailleurs, les risques d'incendie. Dès lors, le rendement thermique supérieur de ce four résulte d'un écart de température plus élevé entre l'agent de chauffage et le charbon à échauffer. Les résultats obtenus ont été particulièrement satisfaisants à Heinitz (Mines Domaniales de la Sarre), où le séchoir en cause précède un four de carbonisation à basse température Salerni.

Il n'y a point lieu de s'attacher ici, d'autre part, à la description et à l'étude des essoreuses continues à charbon (Elmore, Hoyois, Carpenter, etc.). Elles ne semblent point, en effet, donner la possibilité de réduire la teneur en eau des charbons lavés en dessous de 7 pour cent. Leur effet utile doit donc se compléter nécessairement par un séchoir thermique pour arriver à la teneur limite supérieure en eau, soit 2 pour cent, du charbon destiné à l'agglomération.

Enfin, mentionnons l'intéressante méthode de floculation à chaud de la Minerals Separation qui permet simultanément de dessécher rapidement et complètement les charbons flottés et de réduire la

dépense d'agent agglomérant.[2] Vraisemblablement, cet intéressant procédé ne se développera qu'à partir du jour où la pratique du lavage des poussiers et des schlamms par flottage se généralisera. C'est ce qu il faut souhaiter pour le meilleur rendement financier des lavoirs à charbon.

(*b*) *La nature de l'agent agglomérant.*[3]—D'une façon courante on ne se sert que du brai de goudron de houille comme agent agglomérant. De nombreuses tentatives ont été faites, mais sans grand succès, pour découvrir un autre agglutinant. En tout état de cause, le "Comptoir d'achat en commun du brai," qui réunit les Mines allemandes de la Ruhr, a institué un prix de 50.000 marks. pour l'obtention d'un nouveau procédé d'agglomération. On ne connait pas encore le résultat de ce concours, clôs le 31 Mars 1928. Le programme correspondant stipulait que le prix de ce nouveau liant devait se trouver, autant que possible, à l'abri des variations spéculatives et que l'emploi de cet agglomérant ne devait entrainer qu'un minimum de transformations aux installations existantes et que le nouveau procédé ne devait point modifier la qualité des produits obtenus.

D'une manière générale, les méthodes propres à diminuer la dépense de brai ou à substituer à ce dernier d'autres agglomérants, se subdivisent comme suit:

1° Réduction de la consommation du brai par modification des procédés de mélange

2° Succédanés partiels ou totaux du brai:

- (*a*) produits organiques
- (*b*) produits inorganiques.

1° *Groupe—Modification des procédés de mélange*

Procédé Fohr-Kleinschmidt.—Le brai amené à l'état liquide, est injecté sous forme de nuage dans un trommel de 8 m. de long et 2 m. de diamètre où se fait la pâte.

L'économie de brai peut atteindre 20 pour cent, mais si l'on se sert de brai mou, les briquettes se ramollissent et se soudent les unes aux autres par temps chaud.

2° *Groupe—*(*a*) *Substitution totale ou partielle de produits organiques*

Procédé Martel.—Injection de goudron liquide dans une pâte à

[2]Cette méthode a été décrite dans notre ouvrage précité: "Les Combustibles dans l'Industrie Moderne."

[3]On consultera avec fruit l'étude de M. J. Bing: "L'Agglomération" présentée au Congrès du Chauffage de Juin 1928.

dosage en brai atténué. Le goudron peut être remplacé par des huiles de goudron ou du pétrole.

Procédé Liais.—Le brai est additionné de 2 à 5 pour cent de bicarbonate de soude. L'ensemble est ajouté au charbon. La pâte de brai et de charbon doit être à une température suffisante (150°) pour que le bicarbonate de soude se dissocie et que le CO_2 formé diffuse le brai au sein du charbon. Ceci nécessite l'emploi d'un séchoir débitant les charbons à la température de 150°. L'économie de brai atteindrait 50 pour cent à cohésion égale de briquettes qui brûleraient sans fumée.

Procédé Marcesche.—Mélange de brai, de naphtaline et d'anthracène.

Procédé Thornley.—Solution bouillante de lessive d'algue en addition avec du brai fondu.

Méthode américaine.—Mélange d'empois d'amidon, de borax et d'asphalte fondu formant une émulsion épaisse que l'on ajoute au charbon à agglomérer.

Procédé Lehigh Coal.—Emulsion d'argile et de bitume fondu stabilisée par de l acide oléique.

Sulfite de cellulose.—Ce produit permet d'obtenir de bons agglomérés, bien que leur teneur en soufre soit élevée, en raison de la proportion apportée par l'agglomérant.

(*b*) *Substitution totale ou partielle de produits inorganiques*

Ces procédés présentent, par leur principe même, le gros inconvénient d'augmenter la teneur en cendres des agglomérés.

Les substances le plus fréquemment employées sont l'argile et le ciment.

Thyrrel prépare un agglomérant à base de terre d'infusoires et de lessive de soude. Il en suffirait de 2 pour cent pour agglomérer le charbon.

D'après ce que nous avons pu personnellement constater, l'emploi de ces diverses méthodes n'a point permis, jusqu'ici, d'obtenir des résultats véritablement plus avantageux qu'avec le brai. Le plus souvent, à qualité égale des agglomérés, les économies sur la dépense de ce produit ont été plus que compensées par des frais plus éleves pour le séchage, le chauffage de la pâte, le fonctionnement, l'entretien et l'amortissement de fours de cuisson.

Par exemple, on avait espéré beaucoup du recours aux lessives de sulfite de cellulose. Or, en France, tout au moins, ce produit

revient dans les régions du Nord ainsi que sur le littoral de l'Atlantique et de la Manche à un prix égal à celui du brai et certainement davantage, en raison des frais de transport, pour les autres régions minières. Les fabriques de sulfite de cellulose n'existent jusqu'à présent, croyons-nous, qu'en Seine-Inférieure et dans le Pas-de-Calais. D'autre part, le sulfite de cellulose apporte dans les fines à agglomérer, 55 pour cent de son poids d'eau environ, son évaporation forcée nécessite un séchage gradué puis une cuisson vers 400°. Cette dernière opération a pour effet de cokéfier l'agent agglomérant qui, dès lors, à la manière d'une trame, relie les unes aux autres les particules de houille. La mise au point du four correspondant—si elle est devenue réellement effective aujourd'hui, ce dont on peut douter—a entrainé bien des déboires.

En conclusion et jusqu'à plus ample informé, ce que nous serions personnellement heureux de constater, le brai de goudron de houille, combiné ou non avec l'emploi du bicarbonate de soude, constitue le meilleur agglomérant connu des fines de houille. Vu d'autre part, la fabrication réduite de brai de pétrole en France, d'évidentes raisons commerciales notamment mettent obstacle à l'emploi de ce produit.

(c) *Aménagement d'une centrale de préparation mécanique et de dosage du brai*

On sait que le broyage du brai doit être poussé très loin et que, toutes choses égales d'ailleurs, la consommation de ce produit dépend jusqu'à un certain point de la finesse de broyage. Il y a donc intérêt à disposer d'une centrale de broyage du brai. On peut en surveiller efficacement le fonctionnement.

En tout état de cause, les Mines d'Aniche ont installé et mis au point, récemment, une installation de cette nature pour le service de six presses à briquettes. L'intérêt de cette centrale réside surtout dans un travail régulier et dans la réduction, au minimum, des frais de main-d'œuvre et de manutention pour une usine de grosse production.

(d) *Mode d'alimentation des presses d'agglomération*

La maison Sahut Conreur, toujours à l'affût des perfectionnements dans l'agglomération, munit maintenant ses presses à boulets d'un nouveau système de distribution qui possède de nombreux avantages. En voici le principe:

Les boîtes de distribution employées dans les presses à boulets,

même celles qui sont réglables pendant la marche de la machine, ne peuvent faire face complètement aux irrégularités dans l'alimentation des roues mouleuses.

Si les ouvertures dans le fond du distributeur ou les parois intérieures des boîtes s'encrassent, ce qui a lieu surtout dans les angles, les alvéoles correspondantes reçoivent moins de matière et donnent des boulets poreux, à faible cohésion, provoquant des déchets.

Pour y remédier, on doit ouvrir la boîte davantage, mais les alvéoles du milieu reçoivent alors trop de matière et donnent des boulets ouverts ou séparés en deux parties.

Le même inconvénient se produit encore au fur et à mesure de l'usure des frettes mouleuses, usure qui se fait plus rapidement au milieu que sur les bords des rouleaux; on est alors obligé de démonter les boîtes pour modifier la longueur des organes de réglage.

Le nouveau système breveté de distribution supprime tous ces inconvénients.

Les ouvertures dans le fond du distributeur peuvent être de grandes dimensions, ce qui supprime tout risque d'obstruction.

La matière est distribuée sur la largeur des rouleaux au moyen de plusieurs volets articulés, commandés chacun indépendamment. On peut ainsi faire varier à volonté l'alimentation au milieu et sur les bords du rouleau et remédier instantanément aux variations dans la composition de la pâte et à l'encrassement des parois.

Les rouleaux étant alimentés bien régulièrement sur toute leur largeur, leur usure est très régulière et leur durée est prolongée.

Entre le distributeur et les roues mouleuses est interposé un volet à inclinaison réglable composé de trois parties ou volets élémentaires articulés autour d'un axe commun et commandés individuellement par un dispositif composé d'une tringle à extrémité filetée et d'un volant écrou, prenant appui sur une équerre.

En tournant plus ou moins le volant écrou, on déplace la tringle et on fait pivoter le volet élémentaire considéré autour de son axe. La pâte tombant du distributeur, s'écoule d'autant plus facilement que ce volet est plus incliné.

Il est donc possible, à l'aide de ce dispositif, de régler l'écoulement de la pâte sur les bords indépendamment de la partie centrale de manière à obtenir une égale répartition de pâte sur toute la largeur du rouleau.

(*e*) *Forme rationnelle des boulets.*—Des presses fabriquant des boulets d'une forme particulière, ont été mis récemment sur le marché par la maison Sahut Conreur, de Raismes.

Le boulet est représenté par le croquis Fig. 7 de la planche annexe.

Cette forme rationnelle permet une économie d'agglomérant. Les boulets peuvent être beaucoup plus comprimés que les ovoïdes ordinaires. Malgré cette forte compression, ils n'ont pas tendance à s'ouvrir. Ils se démoulent beaucoup plus facilement que les boulets ordinaires.

D'une façon générale, la facilité de démoulage des boulets est d'autant plus grande que ceux-ci sont moins épais, c'est-à-dire que les alvéoles de moulage sont moins profondes.

L'interêt d'un démoulage facile réside dans une économie sensible d'agglomérant, mais l'emploi d'alvéoles peu profondes réduit la production horaire de la presse et, de plus, les bords des boulets plats sont relativement fragiles et s'effritent au cours des diverses manutentions en se transformant en déchets.

Si l'on a recours à des alvéoles profondes, la production horaire de la presse augmente, mais, pour que les deux demi-boulets, agglomérés pendant la compression, soient assez intimement soudés entre eux pour ne pas se séparer au démoulage, il est nécessaire:

1° D'employer une forte proportion de brai

2° De se contenter d'une compression assez faible parce que l'excès de matière introduite entre les roues mouleuses, c'est-à-dire l'excès de compression, donne des boulets qui baillent et qui ont tendence à s'ouvrir.

La nouvelle forme en cause de boulets permet:

- une grande production horaire
- une économie d'agglomérant
- une compression beaucoup plus forte que celle qui peut être obtenue dans une presse produisant des boulets ordinaires
- une fabrication parfaite.

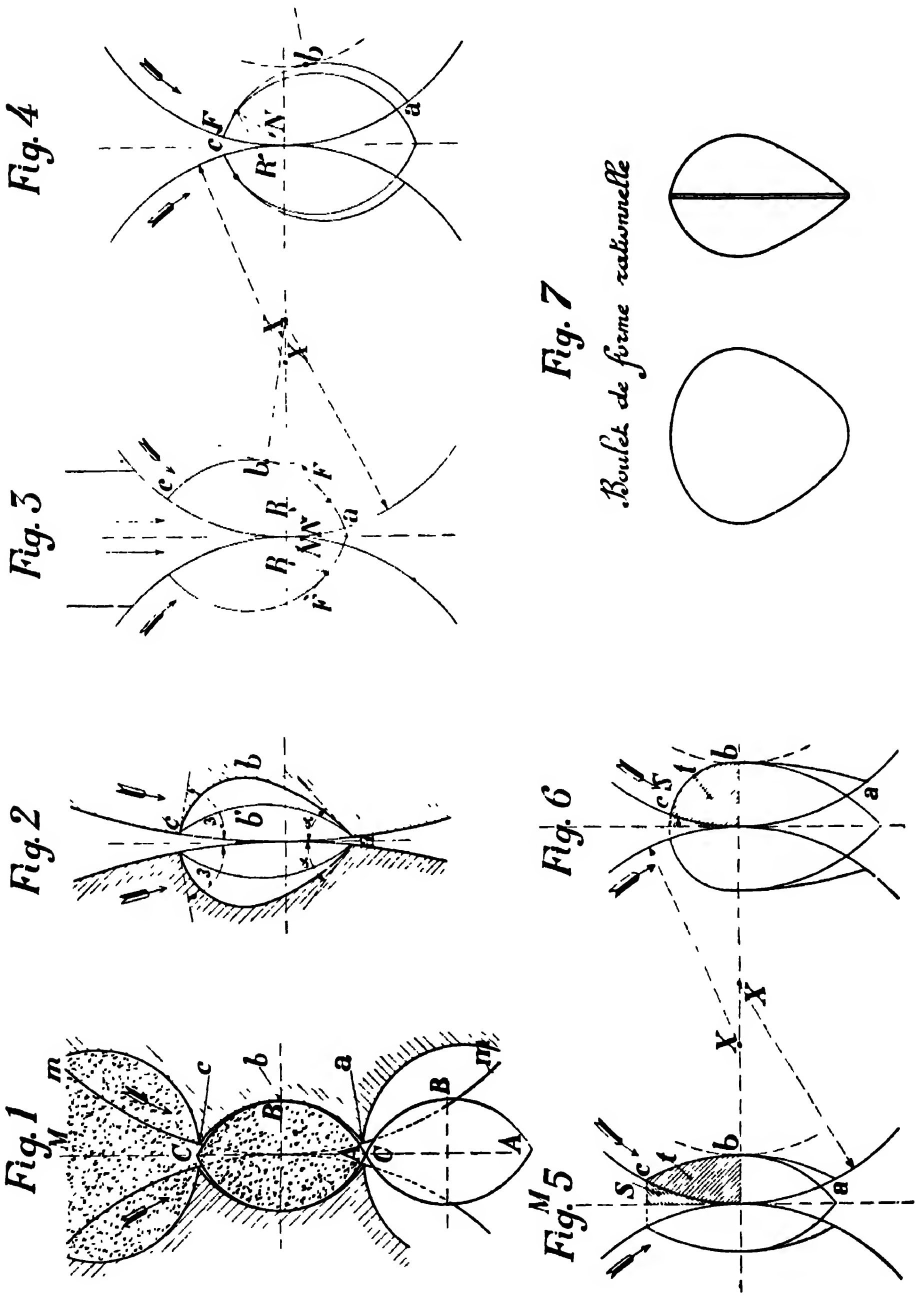
Cette forme spéciale est caractérisée par le profil du fond de l'alvéole qui est une courbe continue dont le rayon de courbure à l'entrée est plus grand qu'à la sortie.

Mais pour qu'on se rende compte des avantages de cette forme, il est nécessaire de rappeler les principaux phénomènes qui se produisent dans la fabrication des boulets.

Les croquis annexés représentent les sections verticales des roues mouleuses.

Dans les presses ordinaires (Fig. 1) les alvéoles présentent un fond dont le profil a la même courbure à l'entrée qu'à la sortie. Les roues mouleuses tournent dans le sens des flèches, l'entrée est en (a), la sortie est en (c). Si l'on réalise le moulage d'une chaîne de boulets, obtenue par des alvéoles disposées dans une même section

transversale des tambours, on peut assimiler cette chaîne à une crémaillère à double denture, chaque denture engrénant avec



la denture correspondante d'une roue mouleuse. Cette chaîne à crémaillère peut être réalisée en faisant passer entre les roues

mouleuses un support constitué, par exemple, par une toile métallique.

La toile métallique représente la droite primitive M.M. de la crémaillère et roule sans glissement sur la circonférence primitive de la roue dentée représentée par la roue mouleuse, c'est-a-dire sur la surface cylindrique M.M. de cette roue. Mais les deux profils conjugués (alvéole et surface du boulet) glissent l'un par rapport à l'autre comme cela a lieu dans les engrenages.

Un examen approfondi de la question permet de se rendre compte que, dans la partie inférieure A.B. de la courbe, les efforts de frottement, conséquence du glissement, ont des composantes opposées à l'effort de compression et d'autant plus grandes que l'angle raccordant la surface (a) (b) de l'alvéole à la surface cylindrique de la roue mouleuse est plus grand. On évitera donc la tendance qu'ont les deux demi-boulets à se séparer en faisant cet angle relativement petit.

Dans les alvéoles ordinaires, si l'angle d'entrée est petit, l'angle de sortie lui est égal et le boulet est plat; mais si on remarque que la partie (b) (c) de l'alvéole provoque, par son frottement sur la surface du boulet, un effort de compression, on voit que cette partie de la courbe peut, sans inconvénient pour le demoulagé, se raccorder sous un angle important à la surface de la roue mouleuse. L'étude montre que cet angle peut atteindre 90°.

Des boulets épais, formés par le tracé (a) (b) (c) de la Fig. 2, démoulent facilement, aussi facilement que les boulets plats du tracé (a) (b') de la même figure.

La forme en cause des alvéoles spéciales se caractérise dès lors par les angles de raccordement avec la surface de la roue mouleuse. L'angle α d'entrée, Fig. 2, est plus petit que l'angle β de sortie, la section de l'alvéole suivant un plan radial pouvant d'ailleurs être quelconque.

On peut étudier l'influence avantageuse de cette forme sur la compression.

Au moment de la compression, la réaction R (Fig. 3), exercée par la paroi de l'alvéole sur le demi-boulet qu'elle a formé est la résultante de la pression normale N, au point de contact et du frottement F, dirigée vers le haut suivant la tangente à la courbe (a) (b) (c). Tant que le point (b), c'est-à-dire le point de l'alvéole le plus rapproché de l'axe de rotation du tambour mouleur n'est pas arrivé sur la ligne XX des tambours, les réactions R sont dirigées obliquement vers le haut. Si la partie inférieure (a) (b) de l'alvéole reçoit un excès de matière, cet excès est, en partie, refoulé vers le haut de l'alvéole. Par contre dans la partie supérieure (b) (c) de l'alvéole

(Fig. 4), la résultante R est, en général, légèrement inclinée vers le bas et l'excès de matière ne peut pas s'échapper. La matière est retenue dans cette partie de l'alvéole et il en résulte que la compression dans la partie supérieure de l'alvéole est plus forte que dans la partie inférieure. Cette surcompression dans la partie supérieure du boulet est d'autant plus forte que le rapport de la surface $(s+t)$ (Fig. 5), à la surface (t) est plus grand. En effet, pendant la compression le volume $s+t$ est réduit jusqu'au volume t. Or, la pâte à boulets emprisonne toujours de l'air et un peu de vapeur d'eau qui sont comprimés pendant le moulage et qui s'échappent au moment du démoulage, en fendant le boulet si cette compression est trop élevée. On observe cet effet sur des boulets bien pressés; la partie supérieure, c'est-à-dire celle qui a subi un excès de compression, est fendue. Pour éviter cet inconvénient, qui est surtout marqué lorsque les alvéoles sont plates, et en outre, longues dans le sens circonférenciel, il suffit de créer dans la partie supérieure de l'alvéole, un réservoir permettant d'absorber l'excès de matière présente en cet endroit et limiter ainsi la surcompression à une valeur admissible. On aboutit encore ici à la forme des boulets épais dans la partie supérieure et effilés à leur partie inférieure que MM. Sahut et Conreur qualifient de rationnelle.

Le rapport $\frac{s+t}{t}$ est, en effet, d'autant plus petit que la partie supérieure de l'alvéole (partie située audessus de la ligne des centres des tambours mouleurs (Fig. 6), est plus épaisse et plus courte. En d'autres termes, pour éviter un excès de compression à la partie supérieure du boulet, il y a lieu d'allonger la partie inférieure au détriment de la partie supérieure, ou, ce qui revient au même, il faut enfler la partie supérieure au détriment de la partie inférieure.

La compression est ainsi régulière, de sorte qu'on peut remplir suffisamment les alvéoles (par l'ouverture convenable du couloir d'amenée de matière et par une charge suffisante dans le distributeur), pour obtenir des boulets épais, bien pressés dans toutes les parties et sans fissures à leurs points supérieurs. La conséquence d'une bonne compression est la réduction du dosage de l'agglomérant.

(*f*) *Appareil de chargement des boulets*.—Tous les fabricants de boulets veulent produire des boulets brillants et d'un bel aspect.

A la sortie de la presse, les boulets sont généralement brillants et ils conservent cette qualité s'ils sont recueillis par un long transporteur qui les déverse en wagons après les avoir refroidis.

Cependant la Compagnie des Mines d'Ostricourt ne desirant produire que des boulets absolument parfaits, a imaginé un dispositif de chargement en wagons qui complète fort heureusement les transporteurs Colson.

Ce système, qui s'installe à la sortie des transporteurs de boulets ordinaires, consiste essentiellement en un châssis mobile sur rails, animé d'un mouvement de va-et-vient, à course réglable, sur lequel est monté un transporteur à bande sans fin recevant les boulets et les déversant dans un ou plusieurs couloirs aboutissant au-dessus du wagon ou du bateau à charger.

L'ensemble est parallèle au grand axe du véhicule à charger et, la course est réglée pour qu'elle soit égale à la longueur de ce véhicule.

Le châssis, monté sur des galets, se déplace d'un mouvement de va-et-vient sur des rails, reposant sur une ossature métallique. Le véhicule à charger peut être soit dans l'axe, soit sur le côté de l'appareil.

La course du châssis est réglée, suivant la longueur du véhicule à charger, par des taquets, placés aux points voulus sur les rails. Le transporteur à bande sans fin avec son tambour-moteur, son tambour et ses rouleaux de support, est monté sur le châssis. Le dispositif de commande du tambour-moteur du transporteur qui est un dispositif par chaîne et le dispositif de commande du mécanisme d'avancement du châssis qui est un mécanisme à engrenages, sont commandés par un moteur unique, monté sur le châssis.

Le transporteur, qui reçoit, en un point quelconque, les boulets du transporteur précédent ou d'une trémie d'alimentation, les conduit audessus d'un plan incliné, placé à l'une des extrémités, qui les fait tomber à son tour dans un ou plusieurs couloirs inclinés latéraux, ou axiaux.

On voit immédiatement les avantages de ce nouveau mode de chargement.

Jusqu'à présent, les boulets chargés en wagons s'amoncelaient en un grand cône et les boulets qui venaient de tomber dans le wagon étaient immédiatement recouverts par les boulets suivants. En cours de chargement, il fallait déplacer le wagon sous la goulotte pour que les cônes successifs emplissent le wagon.

Avec le nouveau dispositif, la course du transporteur, et, par conséquent, de la goulotte, étant réglée d'après la longueur du wagon, il est à remarquer que les boulets se déposent en une couche très mince qui n'est recouverte par la couche suivante qu'après un certain temps, ce qui contribue beaucoup au

refroidissement des produits et au dégagement de la vapeur, et, aussi, atténue les risques de collage des boulets entre eux dans le cas de fabrication anormale.

Le chargement en wagons se fait complètement sans qu'il soit nécessaire de déplacer ce véhicule. Un appareil de pesage peut être installé à l'endroit du chargement et les pesées à vide et en charge sont faites sans aucun déplacement du wagon. On arrête le chargement lorsque le poids voulu est atteint.

Alors qu'auparavant, la partie supérieure du chargement était constituée par deux, ou trois, ou quatre cônes, fatalement irréguliers, elle est constituée, avec ce procédé, par un profil uniforme.

La disposition est susceptible de très nombreuses variantes: les boulets peuvent être amenés sur le transporteur mobile par un appareil de manutention quelconque, ou le transporteur mobile peut vider une trémie d'attente. Le transporteur mobile peut décharger les boulets en voiture, en wagon, en bateau. Il peut les mettre en stock.

Les couloirs de déchargement qui suivent le transporteur mobile peuvent avoir toutes sortes de dispositions.

Modes Nouveaux d'Utilisation des Agglomérés

(a) Données générales sur les anthracites artificiels résultant de la carbonisation de la houille et des lignites à basse et à haute température

De nombreux expérimentateurs se sont efforcés de produire des anthracites artificiels à partir des houilles bitumineuses soumises à une carbonisation soit à basse, soit à haute température. Dans le premier cas, le coke obtenu renferme de 12 à 14 pour cent de matières volatiles au lieu de 4 à 6 pour cent dans le second, mais pour l'un et l'autre, la combustion du produit a lieu sans fumée. Ce résultat est fort intéressant. En Angleterre et en France, on commence à se préoccuper des mesures législatives à appliquer pour que les industriels cessent de déverser dans l'atmospherè des fumées noires également nuisibles à la santé des habitants des villes et à l'entretien des bâtiments. En tout état de cause, on en viendra peut-être un jour à l'obligation de n'utiliser dans les foyers domestiques ou industriels que des combustibles contenant un maximum de 14 pour cent environ de matières volatiles. Ceci impliquerait donc la carbonisation préalable des houilles grasses et bitumineuses.

La proportion maximum de matières volatiles à laisser dans les houilles, à la suite de leur carbonisation poussée jusqu'à une température plus ou moins élevée, sur l'ensemble de leur masse, dépend de leurs conditions d'emploi. Pour les foyers à grille ouverte et à

marche discontinue, on recherche un combustible facile à enflammer; d'où l'obligation de disposer d'un produit à 10-14 pour cent de matières volatiles. Par contre, pour les foyers à marche continue, par exemple les salamandres, les chaudières de chauffage central, les gazogènes fixes et ceux montés sur camions automobiles, il suffit de laisser un maximum de 4 pour cent de matières volatiles. Dans de nombreux cas, on pourrait même descrendre au taux de 1,5-2 pour cent sans inconvénient, tout de même que le coke métallurgique à 1,0-1,5 pour cent de matières volatiles convient parfaitement pour le chauffage central.

Toutes ces remarques ne constituent que des données générales. S'arrêtant à mi-chemin entre ces conditions opposées, l'on voit les Mines de Nœux, par exemple, produire un anthracite artificiel, dénommé "anthracine," à 7 pour cent de matières volatiles. Nous exposerons plus loin comment on le prépare.

La première classe de produits à 12-14 pour cent de matières volatiles résulte de la semi-carbonisation de fines bitumineuses jusqu'à la température de 550° environ, d'après l'un des dispositifs dus à Illingworth (usine de Pontypyrid, près de Cardif), de Zuyderhoudt (usine de Droggenbosch, près de Bruxelles), de Cantieny ou procédé K.S.G. (usine de Karnap, dans la Ruhr). Tous les trois partent de cette remarque que si l'on échauffe lentement la houille dans l'intervalle de température compris entre 350 et 500°, on provoque la distillation des composés β[4] ou éléments auxquels incombe le boursouflement des charbons bitumineux, lors de leur cokéfaction.

Par suite, quand intervient le phénomène de fusion de la houille, vers 450-550°, la masse en cours de traitement se rétracte et le semi-coke engendré se présente, soit en briquettes cohérentes (procédés Illingworth et Zuyderhoudt) que l'on doit concasser avant de les livrer à la clientèle, soit en gros morceaux (méthode Cantieny). On les crible pour séparer les produits du calibre 30-50, de qualité commerciale, tandis que le poussier rentre en fabrication.

La seconde classe d'anthracites artificiels englobe les produits qui se présentent sous l'aspect d'agglomérés. L'anthracine en constitue le type. L'agglomération a lieu, en tout cas, avant la carbonisation. Il convient de retenir que sous réserve d'observer une progressivité de chauffe convenable, on peut préparer ces combustibles à partir de toutes les catégories de combustibles minéraux, depuis le bois, la tourbe, les lignites jusqu'aux anthracites. En ce qui concerne ces

[4] Ce processus a été étudié en détail dans notre ouvrage précité: Les Combustibles dans l'Industrie Moderne.

derniers, des résultats intéressants ont été obtenus à la suite d'essais industriels à grande échelle, terminés à présent d'une façon satisfaisante dans un charbonnage belge. De même, sous l'impulsion habile et tenace du directeur d'une importante houillère française, des résultats nouveaux et intéressants ont été obtenus, à l'échelle industrielle. Il faut souhaiter que les circonstances permettent de les divulguer prochainement.

En attendant et à titre d'exemple, nous résumerons au chapitre suivant la méthode suivie par les Mines de Vicoigne-Nœux-Drocourt.

Auparavant, indiquons les caractéristiques générales auxquelles doivent satisfaire les anthracites artificiels. Ils peuvent s'énumérer comme suit, abstraction faite des remarques précitées relatives à leur teneur en matières volatiles:

Teneur en cendres, 7 pour cent au maximum
Point de fusibilité des cendres, 1.300° au minimum
Densité apparente, 75 kg. à l'hectolitre au minimum

Ce sont là, dans l'ensemble, les principaux chiffres de qualité des anthracites premier choix du Pays de Galles que l'on considère comme le type parfait des combustibles sans fumée. Comme eux, les anthracites artificiels doivent être de grande dureté, resister aux transports et aux manipulations, sans donner de poussier et ne pas souffrir des intempéries.

A ces divers titres, les anthracites artificiels du premier groupe (12 à 14 pour cent de matières volatiles), à cause de leur faible densité apparente (50 à 60 kg. à l'hectolitre) et de la nature fusible de leurs cendres paraissent inférieurs à ceux de la seconde classe (4 pour cent de matières volatiles). Ces derniers pèsent jusqu'à 82 kg. à l'hectolitre.

Quant au point de fusion des cendres, il dépend de l'origine de la houille. Remarquons qu'à quelques rares exceptions près, en France, les cendres sont d'autant plus fusibles qu'elles proviennent de houilles plus riches en matières volatiles. Si cette loi est généralement vraie, elle signifiera que, pour la préparation des anthracites artificiels, il vaudrait mieux partir des fines d'anthracite plutôt que des fines bitumineuses. La question nous apparaissant mûre, nous y reviendrons sans doute avant peu.

(*b*) *Fabrication de combustibles sans fumée, par la méthode des Mines de Nœux*

De la communication de MM. Weiss et Beaugrand au 2° Congrès du Chauffage (Juin, 1928), nous extrayons les données capitales que voici:

"Les produits fabriqués par les Mines de Nœux sont vendus sur le marché sous le nom d' "anthracine." Ils sont faits avec des menus du type ¼ gras à 12-13 pour cent de matières volatiles, additionnés d'une proportion variable de charbon gras ou flambant.

L'agglomération se fait avec du brai dans les presses rotatives du type courant.

La condition essentielle pour l'obtention d'agglomérés denses réside dans la progressivité de la chauffe.

Jusqu'à une température limite qui est variable suivant la nature des agglomérés et oscille autour de 350°, la chauffe peut être conduite très rapidement à raison de 3 à 4° par minute. A partir de cette température limite inférieure, jusqu'à une température limite supérieure qui est également variable suivant la composition des agglomérés et se trouve comprise entre 450 et 500°, la chauffe doit être conduite d'autant plus lentement que la teneur en matières volatiles des agglomérés est plus élevée.

Pour certains agglomérés, il faut descendre au-dessous d'un dizième de degré par minute.

A titre d'exemple, nous citerons les produits obtenus avec des charbons de Nœux, agglomérés contenant 20,6 de cendres et 27,65 de matières volatiles, cendres non déduites.

Un premier essai a été fait en chauffant les agglomérés:

1 h ¾ jusqu'à 250°
2 h ¼ de 250 à 300°
½ h de 300 à 360°
2 h jusqu'à 410°,
puis chauffe rapide au-dessus de 410°.

Les agglomérés qui, avant cuisson, avaient une densité de 1,350, ont présenté, après cuisson, une densité de 1,103. La teneur en matières volatiles des boulets cuits était de 6,5 et les boulets étaient gonflés et déformés.

Un deuxième essai fait avec les mêmes agglomérés a donné des résultats différents.

Dans une première période de 3 heures, on a porté les agglomérés de 0 à 350°, puis pendant 4 heures, on les a laissés sensiblement à la même température, pour terminer par une cuisson plus rapide.

La densité des agglomérés, après cuisson, s'est trouvée de 1,271, la teneur en matières volatiles de 6,8, et l'aspect physique du produit était parfait.

Cet exemple, choisi entre mille, montre toute l'importance de la loi de chauffage."

Les facteurs qui influent sur la qualité et l'aspect des produits sont

très nombreux, parmi eux: la composition de la houille, la finesse du grain, la teneur en eau, la nature et la proportion de liant, le taux de compression, la vitesse d'accroissement de température et sa limite. Tous ces éléments ont été étudiés avec le plus grand soin. Les résultats de ces études ont été publiés dans le numéro de Chimie et Industrie, de février 1928.

Comme agent de chauffage, on recourt à la vapeur d'eau détendue et surchauffée à la température de 650°, mise en œuvre dans des appareils à circulation méthodique, décrits en détail dans la communication en cause de MM. Weiss et Beaugrand. Notons toutefois que le four de distillation de Nœux comprend 8 cellules cylindriques en tôle, régulièrement disposées autour d'un distributeur central constitué par une clé à effets multiples.

Ces cellules ont un diamètre de 3 m, 50 et une hauteur de 5 m, 50. Elles sont munies de deux tampons à blocage par vis et joint en tresse spéciale pour le chargement et le défournement. La masse des boulets est compartimentée dans chacune d'elles au moyen d'anneaux plats de forme spéciale. Ces anneaux sont disposés de telle sorte que la pression qui s'exerce sur les agglomérés aux différents niveaux de la cellule ne dépasse pas des limites acceptables et ne risque pas de déformer les boulets dans l'intervalle de température qui correspond au ramollissement.

Au défournement, les boulets sont dirigés dans un bassin rempli d'eau qui se trouve sous les huit cellules, au moyen d'un couloir muni d'une grille qui élimine le poussier. Ils sont repris par une noria dans laquelle ils sont encore arrosés, déversés dans un trommel qui en retire les boulets cassés, et chargés directement sur wagon.

La capacité de production du four pourra atteindre 400 tonnes par jour, lorsque les installations de production de vapeur seront terminées: aujourd'hui, elle ne dépasse pas 150 tonnes par jour.

MM. Weiss et Beaugrand précisent, d'autre part, que la distillation nécessite une quantité de vapeur qui varie de 1.200 à 1.800 kg. par 1.000 kg. de boulets distillés.

Cette vapeur est produite dans des chaudières timbrées à 20 kg. Elle se détend dans des turbines à faible contrepression qui commandent de puissants alternateurs.

A l'usine de distillation proprement dite est venue ainsi s'ajouter une centrale électrique importante, l'électricité produite venant en déduction du coût réel de la vapeur de distillation.

La production d'électricité atteint 1 kWh. par 10 kg. de vapeur produite

A la sortie des turbines, la température est élevée à 650° au moyen

d'appareils analogues aux surchauffeurs de chaudières, mais dont les faisceaux ont été soumis à un traitement spécial leur permettant de supporter des températures élevées.

(*c*) *Fabrication des anthracites artificiels à partir des houilles bitumineuses et des lignites par la méthode Pieters*

Le procédé utilisé est le suivant: le semi-coke ou charbon sortant du four, à l'état de menu généralement, est finement pulvérisé d'abord; il est ensuite lavé si sa teneur en cendres est trop importante pour en faire directement un combustible de grande valeur, par le procédé de flottage déjà couramment utilisé pour le lavage des schlamms dans les charbonnages. Le produit lavé est ensuite aggloméré à l'aide de brai de lignite ou de houille et les boulets ovoïdes ou briquettes obtenus sont redistillés dans le même four et à la même température que le lignite lui-même. On obtient ainsi un combustible très dur, très combustible, brûlant sans odeur et sans fumée, de première qualité pour tous les chauffages domestiques et industriels. A l'aide de n'importe quel combustible pauvre ou riche, il est possible de fabriquer par ce procédé soit de l'anthracite ou du charbon de bois artificiels, soit du coke métallurgique artificiel, dont les qualités sont supérieures même à celles de l'anthracite anglais et du coke métallurgique ordinaire.

Malgré son apparente complication, ce procédé est cependant fort économique et le prix de revient du nouveau combustible peut être très bas: Ainsi, par exemple, à l'aide d'un lignite de qualité moyenne à 40 pour cent d'humidité, coûtant 50 francs la tonne, il est possible de fabriquer de l'anthracite artificiel de première qualité, à un prix de revient non supérieur à 175 fr. la tonne, compte tenu de toutes les dépenses de distillation, des frais d'entretien et d'amortissement

Un tel résultat découle du concours de deux facteurs importants:

1°—le chauffage économique des fours, permettant de réaliser la seconde distillation du combustible, sous forme d'agglomérés, à l'aide uniquement des gaz permanents résultant de la décomposition du brai utilisé,

2°—la récupération de 60 pour cent environ du brai contenu dans les agglomérés.

L'AUTOAGGLOMÉRATION DES LIGNITES[5]

Il est connu que nos voisins Allemands possèdent et exploitent d'importants gisements de lignite en Silésie, en Thuringe (vallée de

[5]Deux communications remarquables ont été présentées à ce sujet au 2[e] Congrès du Chauffage (Paris Juin 1928):
Moreau—Essais d'auto-agglomération de lignites français.
Bing—L'agglomération.

la Saale et région de Magdebourg) ainsi que dans la région ouest de Cologne.

Les lignites rhénans qui renferment de 50 à 60 pour cent d'humidité au moment de leur extraction, possèdent cette aptitude remarquable de se prêter à l'agglomération sans addition d'aucun liant sous une pression de 1.300 à 1.500 kg. Ceci semblerait résulter que, dans ces lignites, les cellules végétales ont gardé leur forme et que la pression tend à enchevêtrer ces cellules et à en former un feutre. La haute teneur en eau du lignite cru est due à ce que les cellules poreuses retiennent l'eau. On explique par là que des lignites à forte humidité s'agglomèrent assez facilement.

Les opérations de préparation de briquettes de lignite, lesquelles sont de forme connue et présentent comme dimensions: longueur 7 pouces, largeur et épaisseur 2 pouces et pèsent 500 gr., s'enchaînent comme suit:

1° Concassage et criblage du lignite, qu'on pulvérise en dessous de 5 millimètres.

2° Séchage jusqu'au taux de 12-18 pour cent, soit à la vapeur, soit à l'air chaud, soit en combinant ces deux agents.

3° Préparation du lignite séché à la teneur voulue en eau, par criblage, refroidissement, et, s'il y a lieu, mélange de divers lignites pour obtenir la teneur voulue.

4° Pressage, analogue d'ailleurs à celui des briquettes de houille.

Pour produire une tonne de briquettes à 5.000 calories au kilogramme, on consomme environ trois tonnes de lignite cru à 2.100 cal. au kilogramme, savoir: une tonne brûlée pour le séchage et la production de la vapeur nécessaire aux presses et aux moteurs, deux tonnes séchées et agglomérées.

Un spécialiste français, M. Moreau, a recherché si les lignites français se prêtaient à l'autoagglomération. Ses conclusions sont les suivantes, en ce qui concerne l'aptitude de nos lignites à cette possibilité et en raison de cette dernière:

(1) Lignites franchement agglomérables sans précautions spéciales: Voglans, Nouty

(2) Lignites franchement agglomérables, mais en suivant une loi des températures dans chaque section du moule: Laluque, Coudoux, St-Paulet de Caisson

(3) Lignites inagglomérables par les procédés habituels: Valdonne, Gréasque, Caunette, St-Lon, Manosque

En pratique, des usines peuvent être édifiées dès maintenant pour le traitement des lignites de Voglans et Nouty par les procédés connus.

L'agglomération des: Laluque, Coudoux, St-Paulet de Caisson serait mise au point dans l'une des précédentes usines.

Quant aux autres lignites, il est nécessaire de trouver un autre procédé pour les transformer en briquettes.

Relativement aux lignites de la seconde catégorie, leur auto-agglomération nécessite:

1° Leur concassage jusqu'au calibre de 0-3 mm.

2° Leur chauffage jusqu'à la température de 80°.

3° Leur agglomération à la pression de 1.500 kg., le moule étant à la température de 100°.

4° Démoulage après refroidissement de la matrice par un courant d'eau à la température de 40° et en restant sous une pression de 200 kg.

Les briquettes préparées dans ces conditions offrent une résistance à l'écrasement de 150 à 170 kg. par cmq.

Selon M. Moreau, la pression tient la plus grande part dans l'auto-agglomération des lignites, l'élévation de température du moule n'ayant pour effet que d'abaisser la résistance due aux frottements, ce qui permet une répartition plus homogène et plus rapide de la pression sur l'ensemble du combustible.

Seraient agglomérables les combustibles dont le coefficient de frottement des grains les uns contre les autres est assez faible. Ce coefficient serait abaissé par la présence de l'eau et par la chaleur.

Conclusions Générales

Le déclin de l'industrie des agglomérés envisagé au début de ce travail, ne semble point en vue. Il s'en faut même de beaucoup puisqu'une vitalité nouvelle a été infusée à cette technique par des progrès considérables relatifs.

au séchage du charbon
à la réduction dans la dépense de brai
à l'alimentation des presses
à la forme plus rationnelle des produits
à la manutention meilleure des produits manufacturés

Les Mines du Nord, spécialement celles d'Aniche et d'Ostricourt, se sont particulièrement distinguées dans cette voie.

Nous avons vu aussi qu'une nouvelle industrie, celle de la fabrication des anthracites artificiels apparait. Elle est riche en promesses à cause des produits de valeur et des sous-produits fort intéressants qu'elle engendre. Nous en indiquerons bientôt toute l'importance.

On a beaucoup parlé des cadres nouveaux de l'industrie houillère,[6] mais peut-être ne s'est-on pas complètement rendu compte des progrès énormes accomplis, au cours de ces derniers temps, dans les compagnies minières françaises, à la suite d'un labeur opiniâtre. Nous en avons exposé quelques-uns ici. Nous les livrons à l'examen sagace et loyal de nos amis Anglais.

RÉSUMÉ

It has recently been stated that the coal briquetting industry was on the decline. During the last few months important progress has been made in the technique of manufacture. Improvements have been made as regards the drying of the fine coals and the agglomerating agent. New methods of feeding the presses and alterations to the shape of the briquettes have been effected.

In addition there have been important developments in the utilisation of the briquettes. A new industry is springing up, namely, the production of artificial anthracite by the carbonisation of suitable coal briquettes. The process is being worked at the Nœux Mines and consists in heating up the briquettes at a carefully controlled rate. In the methods put forward by Pieters, semi-coke or coke is finely powdered and mixed with tar or pitch and briquetted. The briquettes are then distilled and the main portion of the pitch recovered.

There has also been carried out recently an investigation into the possibility of briquetting French lignite Two areas at least lend themselves to the production of lignite briquettes by the normal process of disintegrating, drying and pressing

[6]Ch. Berthelot—Les cadres nouveaux de l'Industrie houillère—Revue de l'Industrie Minérale—Octobre, 1928.

GENERAL REPORT ON SECTION H

THE COMPOSITION, CLASSIFICATION, PREPARATION, STORAGE AND HANDLING OF GASEOUS FUELS AND OF THE PRODUCTS OF THE CARBONISATION INDUSTRY

T. CAMPBELL FINLAYSON

1 This General Report covers the seventeen papers comprising Section H, namely:—

H1 A Systematic Classification of Technical Gases (Austria), by the Gesellschaft für Wärmewirtschaft.

H2 The Application of the Explosion Principle to Evaluation of the Heating Value of Gases (Austria), by Dr. H. Löffler.

H3 The Testing of Gaseous Fuels (Austria), by Dr. Löffler and Prof. Müller.

H4 The Properties of Gases, defining their Combustion (Germany), by Drs. Bertelsmann and Schuster.

H5 The Production of Gas and the Recovery of other Products by Carbonisation in the Vienna Municipal Gas-works (Austria), by F. Menzel.

H6 Domestic Fuels other than Anthracite (U.S.A.), by U.S. Bureau of Mines.

H7 The Fundamentals of Coal Blending and the Production of Solid Smokeless Domestic Fuel (Great Britain), by Dr. J. G. King.

H8 Gas Manufacture (Great Britain), by Prof. J. W. Cobb, C.B.E.

H9 The Purification of Coal Gas (Great Britain), by Charles Cooper.

H10 Coke-Oven Practice and Developments in Bulk Carbonisation (U.S.A.), by W. H. Blauvelt.

H11 Coal Carbonisation in Japan (Japan), by Yoshikiyo Oshima.

H12 The Manufacture of Gas from Oil (Great Britain), by J. Kewley.

H13 Some Technical and Economic Aspects of the By-product Ammonia Recovery Problem (Great Britain), by P. Parrish.

H14 New Methods of Fuel Analysis (Germany), by Prof. Bunte.

H15 The Development of the Coking Industry (France), by E. Langrogne.

H17 The Gasification of Fuels by Liquid Slag Producers (France), by A. Dessemond.

H18 Modern Methods for the Production and Utilisation of Coal and Lignite Briquettes (France), by C. Berthelot.

2 The subjects covered by this group of papers are somewhat wide in their scope, but for the purposes of a general report they may perhaps be grouped as follows:—

- (*a*) Classification and analysis of gaseous fuels.
- (*b*) Gas manufacture:—
  - (i) Coal gas and water gas.
  - (ii) Gas from oil.
  - (iii) Gasification in liquid slag producers.
- (*c*) Gas purification.
- (*d*) By-product recovery.
- (*e*) The production of solid smokeless fuel.
- (*f*) Developments in bulk carbonisation.

(*a*) *Classification and Analysis of Gaseous Fuels*

3 In a paper presented by the Gesellschaft für Wärmewirtschaft, entitled "A Systematic Classification of Technical Gases" (H1), a standard method of describing and grouping technical gases is proposed. This plan, with minor alterations, has been adopted by the Austrian and German Standards Committee. It is felt that standardisation on similar lines would be of international interest, and the authors suggest that a move in this direction might be looked for at this Conference. The gases are grouped under gases from solid combustibles, from liquid combustibles, natural gases and from non-combustible materials. These groups are further subdivided under process, general nature of gas, particular nature of gas and, finally, calorific value. "The Properties of Gases, Defining their Combustion," are discussed by Dr. W.

Bertelsmann and Dr. F. Schuster (H4). They show that these properties are calorific value, air requirements, flame temperature, speed of ignition, ignition temperature, speed of combustion, explosive limits and speed of explosion. Useful information is given for the determination of combustion calculations.

4 The subject of gas and fuel analysis is dealt with by three authors. Dr. H. Löffler, in his paper on "The Application of the Explosion Principle to Evaluation of the Heating Value of Gases" (H2), gives details of the explosion calorimeter, which is claimed as a speedy method of determining the calorific value of gases to an accuracy of 0.3 per cent. The method depends upon exploding a measured volume of gas mixed with air in a spherical vacuum flask. Ignition is effected at the centre of the sphere, and the rise of temperature measured by a thermometer calibrated to read calorific value. The whole operation takes about three minutes.

5 In a paper from the Austrian National Committee (H3) an account is given of gas analysis apparatus based on the ideas and designs of the late Professor Strache. These consist of a simple apparatus for the determination of carbon dioxide, an instrument for taking temperatures in inaccessible places, an instrument for detecting gas leakages and an apparatus for determining calorific values by explosion. A microcalorimeter is also described, by which it is claimed an accurate calorific value can be obtained from a few cubic centimetres of gas—thus making an assay test more valuable.

6 Prof. Dr. Bunte contributes a valuable paper on "New Methods of Fuel Analysis" (H14), in which he deals particularly with the properties of fuels as they affect the carbonisation industries. The scheme of fuel analysis, as developed by the Gas Institute, includes the determination of the melting point of ash, the coking power of the coal, the calorific multiple of the gas in the case of gas coals, and the reactivity of the coke.

The author recommends that the moisture determination for high bituminous coals should be made by the xylene distillation methods to avoid loss of bitumen or oxidation. He also urges the importance of correct determination of reactivity of carbonised fuels, on which depends the behaviour of coke in gas

producers, etc. Prof. Bunte, in concluding his paper, urges that the World Power Conference should discuss the proposed extension of methods of coal analysis.

(b i) Coal Gas and Water Gas Manufacture

7 The processes and plants for the production of coal gas and water gas do not receive detailed consideration in any of the papers presented at this Conference. This omission is, however, not a sign that there has been an absence of progress in methods of gas production. Prof. J. W. Cobb, in his general contribution on "Gas Manufacture" (H8), shows that the thermal efficiency of the carbonisation process, allowing for the heat used and lost in the manufacture, has increased from 70 per cent. in 1919 to 85 per cent. at the present day for a modern carbonising plant with waste heat boilers. A modern carburetted water-gas plant works with an overall efficiency of about 70 per cent. Prof. Cobb puts forward the suggestion that, with a steam-oxygen blast, a simple continuous gas producer could be designed which would operate with an efficiency of 90 per cent. He mentions that the price of oxygen has not yet been brought low enough. The efforts in many parts of the world to produce cheap oxygen would seem to show that realisation of a supply at a sufficiently low price for employment in gas making is a very long way off.

8 In a paper entitled "The Production of Gas and the Recovery of other Products by Carbonisation in the Vienna Municipal Gasworks" (H5), F. Menzel states that their gas is made either in inclined chambers or coke ovens with outside producers. A complete gasification plant on the Strache principle has also been installed recently. Every effort is made to improve thermal efficiency. This is effected by the low fuel consumption of the coke ovens, the efficient utilisation of coke in central producers, the manufacture of steam from coke dust and the use of excess steam to operate the ammonia and benzol plants.

Professor Cobb, W. H. Blauvelt, and E. Langrogne, in their papers (H8, H10 and H15, respectively), refer to the developments in the use of surplus coke-oven gas for town's supply. Some idea of the magnitude of the use of coke-oven gas in America may be formed from the statement that during 1926, 90 billion

cubic feet of this gas were distributed through city mains. Gas produced from coke ovens is assuming more and more importance as a source of coal gas for city use in America, more coke-oven gas being purchased than coal-gas made.

(*b ii*) *Gas Manufacture from Oil*

9 J. Kewley discusses the manufacture of gas from oil (H12). Gaseous fuel undoubtedly offers the advantages of regularity of firing and ease of control. Considerable quantities of gas from oil are now being made and distributed from central gasworks in localities where oil is cheaper than coal—such as in California. Oil-gas plants are of three types—those which produce enriching gases, those which make oil gas in place of coal gas in central works, and those which make the gas on the site where it is required. The oil gas may be produced either by direct cracking, or by burning a part of the gas to supply the heat necessary for cracking the rest, or finally, by making gas from interaction between highly heated oil and superheated steam. The author states that on large plants the oil consumption is 5.65 imperial gallons per 1,000 cu. ft. of gas of 500 to 600 B.Th.U. per cu. ft. In the direct cracking process the process is intermittent, the chambers being heated by air blast containing a little oil.

10 Continuous plants are built which work on the principle of effecting cracking by the heat supplied by partial combustion of the oil. Reference is made to the Hakol-Zwichy process, in which conditions are so controlled that no carbon is deposited. When the gas is used for direct firing about 95 per cent. of the heat value of the original oils is available in the form of hot gas; if cooled, about 80 per cent. of the heat is available. The Dayton plant, which operates on the same principle, is very compact, the output being 666 cu. ft. per sq. ft. of ground space per day, with one man per shift to operate the plant.

11 Mention is also made of the Goldsborough processes for the production of high calorific value oil gas, which are at present in the development stage.

(*b iii*) *Gasification in the Liquid Slag Producers*

12 With the object of utilising low-grade fuels, such as coal and coke screenings, a slagging gas producer has been developed in France. This is described by A. Dessemond (H17). The

slagging gas producer is fed with shale or screenings and coke breeze, scrap iron and limestone. The producer is 2½ metres diameter and 11½ metres high and handles 100 to 150 tons of material per twenty-four hours, producing about 200,000 cubic metres of gas of about 1,200 calories per cubic metre. The blast is pre-heated in metal recuperators heated by producer gas. The products available for sale per twenty-four hours are about 60 tons ingots and 40 tons of slag, which, when mixed with lime, is used for cement manufacture. The producer gas, after cleaning, cooling and washing, is used for heating purposes, either alone or enriched with coke-oven gas.

(c) *Gas Purification*

13 Charles Cooper, in his contribution on the "Purification of Coal Gas" (H9), gives a comprehensive survey of the cooling and condensation of gas, tar extraction, ammonia washing and gas drying. Dealing with cooling, the author compares water-tubed condensers and washer coolers. The latter consist of towers filled with suitable packing, over which the cooled condensate is caused to circulate. He shows that, although the washer cooler is cheap, it involves considerable pumping and increases the formation of toxic constituents, which cause trouble in sulphate plant effluent disposal. Discussing tar extraction, Cooper states that the Cottrell process of electrical precipitation gives good results, but the cost of an installation is about three times that of a P. and A. apparatus. This author also gives consideration to the principles and methods of ammonia washing, and compares the theoretical and technical advantages of mechanical and tower washers. The process of drying coal gas prior to its distribution has been the subject of discussion in recent years, and the views expressed by the author will, therefore, be studied with interest. He compares the four main methods of dehydration, compression, refrigeration, chemical and physical absorbtion and adsorbtion. In his view, the most economical process is the drying of gas by means of a solution of calcium chloride, which is simple to operate and costs less than ¼d. per 1,000 cu. ft. of gas treated.

14 W. H. Blauvelt, writing on "Coke-Oven Practice and Developments in Bulk Carbonisation" (H10), shows how the operation of a coke-oven plant and the yield of by-products have been improved by the spraying of the hot gas in the collecting main

with hot liquor at about 80°C., which causes the tars to come down and eliminates pitch troubles and consequent pipe cleaning. The best results are found with 45 gallons per hour per ton of coal coked per day. The same author also mentions the use of liquid purification for the removal of hydrogen sulphide, which he regards as a notable step forward in the technique of gas purification.

(*d*) *By-Product Recovery*

15 The carbonisation industries are at the present time faced with a serious problem in connection with the disposal of ammonia, and therefore, the contribution by P. Parrish on "Some Technical and Economic Aspects of the By-product Ammonia Recovery Problem" (H13) is particularly opportune. The author shows that whereas the largest by-product works produces 25,000 tons of ammonium sulphate per annum, Billingham, according to the modified schemes propounded by Lord Melchett at the Adriatic Conference, will produce 360,000 tons per year. P. Parrish urges that the recovery of ammonia at the majority of works should only proceed to the point of making either a concentrated gas liquor containing 15 per cent. NH_3 or a solution of ammonium sulphate containing 40 per cent. $(NH_4)_2SO_4$. These concentrated liquids should be converted into ammonium sulphate of uniform quality at a central works. The production of ammonium sulphate from anhydrite (calcium sulphate) is also dealt with, and the author compares the technical and economic aspects of the anhydrite process in comparison with the standard sulphuric acid process. He shows that for the treatment of by-product ammonia, the anhydrite process requires a far more complicated plant than does the standard sulphuric acid saturator plant. The plant involves crushing, grinding and screening machines, reaction vessels, CO_2 purification plant, special filter presses, evaporation plant and rotary driers.

16 The economics largely depend upon the price that anhydrite can be purchased at works. P. Parrish considers that the anhydrite process has an advantage in price varying from 8/8 to 20/8 per ton sulphate of ammonia. He considers the process would not work economically on a plant designed to deal with less than 30 to 40 tons of ammonium sulphate per day.

(*e*) *The Production of Solid Smokeless Fuel*

17 The subject of smokeless fuel production is discussed in a number of the papers. Probably the outstanding paper is that by Dr. J. G. King on "The Fundamentals of Coal Blending and the Production of Solid Smokeless Domestic Fuel" (H7). The author gives a very valuable historical survey of the stages in the development of the process of blending, apart from including much information from his own research work. He shows that from the point of view of smokeless fuel production the blending of coals must be done by careful selection to ensure the right distribution and behaviour of the binder. He considers that the strongest cokes are obtainable by fine grinding of both constituents, but that the diluting particle may, if a suitable coal, be of larger particle size. When the diluent is coke it must be finely divided. He believes that the period of carbonisation of blends of coal should be such that the volatile matter remaining in the coke is 6 to 8 per cent. Where coke is the diluent this does not appear to be so important.

18 J. W. Cobb, in his contribution (H8), emphasises that low-temperature carbonisation is not the only way of producing solid fuel of high chemical reactivity which will burn cheerfully, and states that interesting results have been obtained in making coke more reactive by the addition of inorganic constituents, such as sodium carbonate, oxide of iron and lime. It is not claimed that the use of such cokes has yet reached commercial application.

19 In Japan, work has been carried out by the Imperial Fuel Research Institute on the subject of reactivity of coke, details of which are given by Yoshikiyo Oshima, entitled "Coal Carbonisation in Japan" (H11). Experiments are being conducted in regard to the improvement of coke manufacture, particularly from the point of view of determining proper carbonising conditions for Japanese coal.

20 In a paper from the U.S. Bureau of Mines on "Domestic Fuels other than Anthracite" (H6), it is shown that coke-oven coke is being successfully sold in competition with anthracite in many parts of America. There is a steady increase in the number of merchant plants, not connected with blast furnaces, which are engaged chiefly in the manufacture of foundry and domestic cokes. The American merchant plants in 1927 sold nearly 40 per

cent. of their coke output for domestic use. The volatile matter of such coke averages 0.7 to 2.0 per cent. and ash 7 to 15 per cent. All the coke is sold in carefully screened sizes.

21 C. Berthelot, in his paper on "Modern Methods for the Production and Utilisation of Coal and Lignite Briquettes" (H18), describes a new industry which is being developed in France for the production of artificial anthracite by the carbonisation of suitable coal briquettes.

22 The process consists of heating up the briquettes at a carefully controlled rate. Alternatively, semi-coke or coke is finely powdered and mixed with tar or pitch and briquetted. The briquettes are then distilled and the main portion of the pitch recovered.

(*f*) *Developments in Bulk Carbonisation*

23 Three papers deal with bulk carbonisation. W. H. Blauvelt, writing on "Coke Oven Practice and Developments in Bulk Carbonisation" (H10), traces the modifications from the old Beehive oven to the modern by-product oven. The largest ovens in America to-day have a capacity of 20 tons per charge. Coking times have been greatly reduced, and one plant has a record of two months' operation at more than 1.3 inches per hour. This increase per unit of plant capacity and per man hour has to a large extent offset the greatly increased cost of construction and wage rate since the early days of the industry. The author includes a valuable statistical summary of the United States coke and by-product industry.

24 The U. S. Bureau of Mines, in their contribution "Domestic Fuels other than Anthracite" (H6), also give in a diagrammatic form invaluable data relating to the economics of the coking industry. They show that a large number of coke-oven installations have been erected specifically for the supply of town's gas.

25 Dealing with the development of the French Coking Industry (H15), E. Langrogne shows that coke quality has been improved by compression of the charge, high carbonising temperatures and reduction of coking time, the latter being obtained by the adoption of narrow ovens of silica material. Blending is now largely practised, and has only been made possible by the use of modern ovens.

DISCUSSION

THURSDAY, SEPTEMBER 27 (MORNING)

Section H

THE COMPOSITION, CLASSIFICATION, PREPARATION, STORAGE AND HANDLING OF GASEOUS FUELS AND OF THE PRODUCTS OF THE CARBONISATION INDUSTRY

Chairman: MR. JOHN TERRACE (Great Britain)

THE CHAIRMAN called upon the General Reporter of the Section to read his General Report.

MR. T. CAMPBELL FINLAYSON read his Report.

MR. E. V. EVANS (Vice-Chairman, Great Britain), with a view to stimulating discussion, reviewed very briefly the papers presented. In the paper by the Gesellschaft für Wärmewirtschaft (H1), he said, there was a wonderful example of what might be called "the will to standardise." Dr. H. Löffler, in paper H2, had described a very ingenious explosion calorimeter, but no doubt he would be very appreciative of the fact that one of the most difficult operations in calorimetry was the measurement and correction of gas volumes. Dr. Löffler, while in this country, would find it interesting to take the opportunity of inspecting the recording calorimeter invented by that ingenious genius Professor Vernon Boys. Commenting on paper H3, he said it was certain that British and Austrian physicists had much to learn from each other on the question of calorimetry, and he expressed regret that there was no contribution on the subject by a British physicist which would serve to indicate the degree of accuracy attained in this country to-day. Among other papers, he referred to that of Herr Menzel (H5) as of particular interest, as showing the line of development in the leading gasworks of Austria, namely, those of Vienna. One saw in the background of the development the mind of the late Professor Strache. All nations had much to learn from Vienna, though many might criticise the policy of complete gasification. Mr. Evans specially commended as one very suitable for debate the carefully-prepared paper by Dr. J. G. King (chief chemist to the Fuel Research Board). This paper (H7) dealt with the present position of solid desructively-distilled fuels as seen through the eyes of the British Government's research station. Dr. King had forecast indirectly that the blending of coal was essential if it was required to produce a coke the characteristics of which might be controlled; and the paper was of fundamental importance to the coal carbonising industry, and perhaps particularly to the gas industry. Professor J. W. Cobb (of

the University of Leeds), in his paper (H8) had emphasised the need for high thermal efficiency in gas manufacture. Already Professor Cobb, in collaboration with other eminent investigators, had shown that the process of gas manufacture was one of very high thermal efficiency as compared with that of the generation of electricity, and this attribute of efficient coal conservation was one of which the gas industry was justly proud; it was indeed one of the most valuable assets it possessed. In discussing questions of coal carbonisation it might be said that the subject divided itself broadly into three main compartments: (1) the question of the thermal efficiency of the process, which was discussed by Professor Cobb; (2) the question of economic manufacture from the point of view of design of plant and the adequate utilisation of machinery and labour; and (3) the distribution of the thermal energy of coal into the compartments gas, tar, coke, and free carbon. Professor Cobb had urged the industry further to increase efficiency, and his contribution was of vital interest. He also deplored, as did all of us, the fact that oxygen was not yet available for our use industrially and, finally, he had questioned whether coke might be made so reactive by the addition of inorganic compounds that the necessity for applying the process of low-temperature carbonisation for the production of a highly-reactive semi-coke would disappear. This was a highly contentious question. Mr. P. Parrish, appalled by the continued reduction in the value of by-product ammonia (paper H13), had submitted for consideration methods which might increase the revenue of the coal carbonising industry from this source. His plea was for centralisation, but he was all along the line faced with the difficulty of transport costs. His suggestions for dealing with the problem merited close consideration. M. Dessemond, in his paper on the gasification of fuels by liquid slag producers, had made a statement with regard to the quality of cement produced which was the gist of the whole matter. We were all interested in fusion producers, but we had to consider not only the ease of working, but also the effective disposal of the cement which was the by-product of the process. M. Dessemond had said that the plant referred to was making 60 tons of cement a day, and he had also made the emphatic statement that this product was comparable in its qualities to the best Portland cement. That was a most important matter. In building construction to-day the main costs were probably those in respect of labour and the transport of material to the site. Thus, he believed it would pay always to use none but the very best of cements; it followed that a second-quality material would not be easily disposed of.

Finally, Mr. Evans congratulated the Section on the excellence of the papers presented, and took the opportunity to express thanks to the authors.

THE CHAIRMAN said that the list of subjects for discussion, as given at the end of the General Report, was very helpful, and he suggested that some of the most important points to which the discussion might with advantage be directed were those relating to the

production of smokeless fuel, the technical and economic aspects of drying gas before distribution, and the technical and economic aspects of ammonium sulphate production. At the same time, he did not wish to stifle discussion upon any of the other points enumerated in the General Report.

MR. JOHN ROBERTS (Great Britain) stressed the importance of the work the results of which were recorded in the valuable paper by Dr. J. G. King on the blending of coal and the production of smokeless fuel (H7), and emphasised particularly the importance of Dr. King's conclusion No. 5, that of the 10 million tons of coke produced annually for sale a high proportion could, by the methods suggested in the paper, be made suitable for domestic consumption. He (Mr. Roberts) had been interested in a number of experiments carried out on a large scale with a view to improving the quality of gas coke and furnace coke in order to render it suitable for use in the open grate, and he had been surprised at the simplicity of the method. In the experiments carried out at Ramsgate on the Woodall-Duckham intermittent vertical retorts the temperatures employed for gas making were not disturbed in any way. The highest temperature was about 1,350°C. The blend, which, of course, had had to be tudied and prepared carefully beforehand, was placed in the retort, and instead of heating it for twelve hours it was heated for eight hours, and the fuel produced was very much superior as a domestic fuel to that produced normally in the same retorts. Dr. King's work appeared to have been confined chiefly to horizontal retorts, but, whilst this system was applicable in certain cases to horizontal retorts, he could imagine circumstances in which it would not be successful. The main object of the work with which he (Mr. Roberts) had been associated was to produce the same fuel in coke ovens. Incidentally, he said, Dr. King had referred to the early experiments of the Woodall-Duckham Company as having been carried out in a narrow oven, but that oven was actually a 19-in. oven, *i.e.*, a wide oven. The experiments with that oven were not successful, but it was learned how the job should not be done, and sufficient information was gathered from the experiments to indicate that success was extremely likely in a narrow oven, say 14 in. wide, heated uniformly and efficiently. The early experiments were carried out in an old oven which he believed had since been scrapped. Although the method might sound simple, the coals had to be studied very carefully and blended, but once the right blend was obtained, the method was particularly simple. Prior to these experiments he had prescribed that from 3 to 8 per cent. of volatile matter was required in the coke in order to render it readily combustible, but as the result of the Ramsgate experiments he had concluded that it was not really necessary to have a volatile content of more than about 5 per cent., so that the prescribed range was being reduced from 3-8 per cent. to 3-5 per cent. A good many people seemed to think that a low-temperature fuel must contain from 8 to 12 per cent. of volatile matter. If one wanted to produce domestic fuel, however, or if domestic fuel were to be the chief

product, it was not really necessary to work at low temperatures; but if one required high yields of oils that was another matter. The high-temperature system of manufacturing semi-coke was only a partial solution of the domestic fuel problem, and he could conceive of several low-temperature processes being successful; there was plenty of room. The results described by Dr. King had received support also from the paper by W. H. Blauvelt (H10), in which it was shown that the coke produced was much improved as the result of blending. Reference was also made in the latter paper to a free-burning cellular coke, it being stated that one of the characteristics of recent coke oven operation in the manufacture of blast furnace coke was the production of a free-burning coke having a well-developed cell structure, more reactive to the oxygen of the blast than was formerly thought practicable. He (Mr. Roberts) drew attention to the possibility of making, at a lower carbonising temperature (not a lower flue temperature) a fuel more reactive in the blast furnace than the ordinary blast furnace coke. Mr. Blauvelt had stated that in the practice he had referred to it was usually desirable to finish the coke at a temperature of about 1,100°C. Mr. Roberts questioned, however, whether Mr. Blauvelt really meant that he was going to burn it off at 1,100°C., and said he would not have thought that one would have obtained a more free-burning coke by heating it to a temperature higher than 800°C. Mr. Blauvelt's remark did not appear to be in agreement with the statements made by other workers in earlier publications, and it would be of great interest if those concerned with blast furnace practice would investigate fully the most desirable temperature at which blast furnace coke should be made.

Dr. R. H. Griffith (Great Britain) dealt with some experiments carried out by The Gas Light and Coke Co., in connection with the manufacture of gas from liquid fuels, having in view its use for the enrichment of water gas. When an oil was converted into permanent gas there were four main factors which influenced the results:—(1) The rate of passage of the oil through the cracking chamber; (2) the temperature and pressure of reaction; (3) the atmosphere in which the process is carried out, and (4) the character of the oil. Experiments had been carried out in these four directions and all the results were worked out on a thermal basis, *i.e.*, the number of therms obtained as gas from one gallon of oil had been considered in relation to some other factor. (1) Using one particular oil, the influence of the time of contact between oil vapour and the hot zone was studied in an atmosphere of hydrogen and at a constant temperature; it was found that the yield of therms per gallon increased to a maximum as the rate of oil feed increased, and then fell again steadily. This meant that there was an optimum speed of input for a particular oil in a given plant at a fixed temperature, and the same principle holds for oils of all types. When the cracking surface was doubled without material alteration of the other conditions it was discovered that the reactions involved did not occur only on the hot surface but to a considerable extent in the gas phase also. Repetition of these tests

in nitrogen gave results of the same kind and it was clear that no distinction could be drawn in this way between cracking or hydrogenation reactions, because both occurred in the gas phase and on the hot surface. At the same time, the great increase in absorbtion of hydrogen at low rates of oil input showed that the hydrogenation reactions were comparatively slow and that it was this absorbtion which led to loss of efficiency when the oil feed was not sufficiently rapid.

(2) On the ordinary water gas plant pressure changes were very small, but temperature could be altered over a wide range; the maximum thermal yield of gas had been measured between 650 and 850°C. and the best results were obtained at or about 750°C.

(3) The atmosphere in which cracking occurred would influence operation by the amount of hydrogen it contained; the importance of this point had already been mentioned.

(4) The character of the oil which was used for gas making would naturally have a considerable influence on the results, and Mr. Kewley had pointed out the need for information in this direction; a very brief summary of recent work on the subject would be given. After a great deal of preliminary work, the method of oil analysis described in the Journal of the Society of Chemical Industry, 1928 (21T), was adopted and about thirty different oils were examined in this way and with respect to their behaviour on cracking under standard conditions. Yields varying from 0·5 to 1·45 therms per gallon were obtained, and comparison of the figures with those of analysis showed that hydrocarbons having a cyclic structure were far less valuable than those built up with open chains, so that although the cyclic bodies might well give rise to some gas, yet a qualitative valuation of an oil could be made by regarding all cyclic constituents as useless.

Finally, he mentioned some results obtained on a full scale water gas plant. The rate of oil feed to a carburettor could be varied over a wide range even when the number of gallons consumed per run was not altered, so that in this direction there was obviously scope for development. Tests had been made in which the cracking temperatures were kept as steady as possible and the rate of oil injection was varied; the yield of therms per gallon was measured by careful observations of the necessary quantities and by calculations from gas analyses, and the results were exactly similar to those obtained on the small scale. A good deal more information of the same kind, such as figures concerning absorbtion of hydrogen and variations in the quality of the tar produced, had been derived from this work, and it was hoped shortly to publish an account of the whole.

DR. H. LÖFFLER (Austria), in amplification of his paper on calorimetry by the explosion method (H2), said he was very well acquainted with the English and American apparatus of this type, having given a lecture on the subject recently. The field of application of this type of apparatus was different from that of the usual calorimeter The explosion calorimeter was transportable, and it

might be applied for testing at different stages of the production of gas. It also applied to the testing of very small quantities of gas as obtained in experiments. One point he stressed concerning the accuracy of the explosion method of calorimetry was that relating to the ratio of air and fuel burned in the explosion. If the quantity of air were too small, or too large, either the explosion would not take place at all, or incomplete combustion occurred. It was essential, therefore, that the proper mixture of air and gas should be obtained in the explosion chamber. He illustrated his point by reference to diagrams giving the exact figures as to the mixture desirable, and said that he used ratios of fuel to air of from 1-3 to 1-7.

MR. L. H. SENSICLE (Great Britain) said he wished to refer to the paper (H13) by Mr. P. Parrish. In that paper on page 452 appeared the statement, "In the writer's view there is no such thing as a direct process of ammonia manufacture. It is true that coke-oven plants are said to operate the direct process, but the last-named is more imaginary than real." He felt sure that Mr. Parrish had inserted these remarks as a form of challenge to delegates experienced in such processes to come forward and relate their experiences, otherwise there could be no justification for the remarks. He would like to assure Mr. Parrish that in the North of England were direct recovery plants which had been in continuous and satisfactory operation for a number of years, and he knew that there were members present who could point to similar plants in the Midlands. Referring to the objection that ammonium chloride was carried forward to the saturator, and that the dissociation forming hydrochloric acid caused corrosion troubles, it was necessary to point out that the ammonium chloride did not reach the saturator, but was effectively removed by the spray of liquor in the rotary tar extractor.

Then there was the statement that "the quantity of tar is not nearly so satisfactory as that yielded by the semi-direct or indirect processes. In some cases it resembles pitch rather than tar." It was only necessary to say that the tar produced in the carbonising plant could not vanish mysteriously, and was certainly not destroyed by the direct process of ammonia recovery. Mr. Parrish had missed the main point, which was that in the process a kind of fractional condensation took place. The heavy tar came down first, and after the saturator the light oils, containing much of the tar acids and naphthalene, were condensed separately. A normal tar could be obtained by mixing these two fractions, but it was worth mention that advantage could be taken of this early separation. At one plant the heavy tar proved to be of right viscosity for tar macadam manufacture. It was merely dehydrated to 1 per cent. water by centrifuging and dried to ½ per cent. water by aeration with compressed air. Tar of any suitable viscosity could be obtained by admixture of the right amount of light oily condensate. It was also a very favourable point that the heavy tar formed had a low naphthalene and phenol content—both points tending towards suitability for road purposes. The light oily condensate was run

into special tanks and the naphthalene separated on cooling centrifuged and hot-pressed. Washing of the oily condensate for tar acids was contemplated.

Referring to the so-called "devil water," it was true that an aqueous condensate was obtained after the saturator. This effluent had the advantage that it contained phenols amounting to about 400 parts per 100,000 and that thyocyanate and thiosulphate were practically negligible. Thus the oxygen absorbing power was almost entirely due to phenols. The latter could be extracted by a benzol washing process which had been operated with a margin of profit elsewhere. Thus the direct recovery process had distinct potentialities for the solution of the effluent problem.

Mr. Parrish had stated that the undecomposed steam resulting from steamed vertical retorts would amount to 10-15 per cent. by weight of the coal throughput. This seemed a rather high figure, but it would not necessarily prove an obstacle to the success of direct recovery in such cases. It would be remembered that gasworks carbonised dry coal, while coking plants often used washed coal containing upwards of 10 per cent. of added water. These plants worked direct recovery successfully, and the added water was comparable with that in the vertical retort case cited.

Consideration of the water liberated from the acid used would show that even in the case of 70 per cent. acid the weight of water amounted to less than 1 per cent. by weight of the coal carbonised, and hence this factor was not of serious importance

Mr. Parrish had indicated a preference for the semi-direct process; but it seemed that this process involved some of the unnecessary expenses of the indirect process such as expenditure on stills and liming plant, steam consumption, etc. The fact was that the direct process had originally proved troublesome to operate and had gained a bad name, but in recent years the initial difficulties had been overcome, the conditions for success were better understood, and it could now be stated that a number of plants had been working uninterruptedly for several years without appreciable loss of ammonia and with marked ease of control. He would be glad to show Mr. Parrish such plants in operation.

Dr. G. Egloff (U.S.A.), referring to the paper by Mr. J. Kewley on the manufacture of gas from oil (H12), and the statements made in it with regard to the gas made in the usual cracking process, said he presumed the cracking process referred to was the one used primarily for the production of gasoline, which operated at a temperature of approximately 475°C. That process was not yet in extensive use in Europe, but in the United States in 1927 it had produced over 200 billion (200 thousand million) cu. ft. of gas at a temperature of approximately 475°C., and a large portion of that gas was used by the gas companies for enriching their water gas. In some plants the gas from the cracking process was re-cracked at a very high temperature, so as to increase the volume of the gas and to reduce its thermal value from approximately 1,200 to something of the order of 550 B.Th.U. per cu. ft. The use of the gas

arising from the distillation of crude oil had resulted in a reduction of the quantity of gas oil used. The Gas Company at Los Angeles obtained natural gas and cracked it down into hydrogen and carbon, because the quantity of hydrogen in the natural gas was about three times as great as in the retort gas; and then blended the two gases and burned them. As illustrating the size of the natural gas industry of the United States, he said that in 1927 the public there had consumed something like 1,700 billion cu. ft. of natural gas, and that was a relatively small proportion of the total gas burned in the United States. Gas making was a very live subject there.

MR. S. DE WAARD (Holland) referred to the paper (H14) by Prof. Bunte, of Karlsruhe, because he said this paper gave, in his opinion, a poor summary of the different properties of coal and other solid fuels. These properties were of great importance when burning fuels in heating apparatus (boilers, or gas producing apparatus), and also for the comparison of these fuels in one apparatus or of one fuel in several heating apparatus. The importance of these properties together was also the reason why in Holland they used the gross calorific value. Used alone, the gross calorific value was of as little importance as the net calorific value, but when both were used the gross calorific value had the advantage that it always focussed attention on the real losses which the use of a certain fuel with a certain apparatus involved. In his opinion, however, the knowledge of the properties of fuel and the testing methods—not that all these methods should be used without criticism or change—was far more important than the theoretical classification of fuels. Fuels could always be used in an excellent manner when their properties were known without knowing anything about classification; but that could not be done when only knowing part of the classification. He would say, also, that use could not be made of all the important properties in one classification.

DR. W. VON HOHENHAU (Germany) discussed a process which he claimed to have perfected to enable water to be used as a fuel, after its constituents had been decomposed. His theory was based on a theory put forward by Sir Oliver Lodge many years ago. It was impossible, he said, to give the results of thirty years' work in the limited time at his disposal, but his experiments had shown that by applying to water very high electro-magnetic vibrations he was able to release the hydrogen from the water and to extract further hydrogen from the oxygen. The fundamental element was hydrogen. The vibration range used to release the hydrogen was from 500,000 to 5,500,000 per second. In treating water, he destroyed first the balance of the compound H_2O, after which he treated the oxygen structure separately. He did not use a catalyst, but plain electromagnetism. In treating the oxygen he was using a vibration range of from 3,250,000 to 4,800,000 per second. By activation, the magnetic force holding the oxygen structure together was overcome and the cracking of the structure took place. From one atom of water he obtained eighteen atoms of hydrogen, and the heat units obtained from hydrogen had run an internal combustion

engine for fourteen days. There were about 180 cu. ft. of hydrogen to 1 lb., and 1 lb. of hydrogen contained about 25 H.P. The hydrogen could be used as a gas for power purposes. The apparatus by which he was able to create energy in this way occupied very little space. He appreciated, he said, that he would probably be laughed at; but other scientists, such as Lodge and Einstein, had been laughed at before. In this connection he recalled that at the international convention of the Association of Science, in Philadelphia, in 1927, Einstein had been called a swindler, and had been ridiculed for four days continuously. On the last day of the convention, however, Dr. Crooker, of the Smithsonian Institute, had been awarded the gold medal of the Association for his extension of the Einstein theory. That proved how much scientists knew of each other.

Finally, Dr. Hohenhau promised that at a later date he would submit the papers concerning his process to the World Power Conference.

MR. E. KILBURN SCOTT (Great Britain), in a criticism of recent proposals to transmit coke-oven gas to gasworks for towns' supply, pointed out that some coke ovens were remote from towns, and, in cases where mains had to be laid in ground under which mining operations were carried on, there was likelihood of pipe joints being opened by subsidences.

The cost of the gas when it reached the town might well be higher than the cost of the gas made at the gasworks; besides which there was a personal factor to be considered, namely, that the employees of gasworks naturally clung to their jobs, and especially so in municipal works.

Coke-oven gas contains a great deal of hydrogen, and by stripping this it could be used for making into synthetic ammonia, as was being done at many places on the Continent.

Some years ago, he reported to a coke-oven company in the North of England where gas had been burned to waste at the rate of about 2½ million cu. ft. per twenty-four hours, for years. The gas contained about 53 per cent. of hydrogen, and he showed that by stripping this the gas remaining—about one million cu. ft.—was more than sufficient to provide the necessary heat, etc., for the works. Then the quantity of hydrogen stripped out of the gas was enough to make synthetic ammonia by a Claude plant at the rate of 10 tons of pure anhydrous ammonia per twenty-four hours. Once the nitrogen was fixed there was no limit to what could be done with it.

The value of the original gas was improved as the result of stripping the hydrogen, because the calorific value of the original gas was about 570 B.Th.U. per cu. ft., and the calorific value when stripped was over 800 B.Th.U., the calorific value of the hydrogen extracted being 344 B.Th.U.

The gas remaining after stripping the hydrogen was better than the original gas for gas engine purposes, because too much hydrogen was a nuisance in gas engines, as it made them run "poppy."

In the Claude process the pressure was about 14,000 lb. per sq. in., and yet it was easy to keep the joints as tight as that pressure, and the catalycr bombs of nickel chrome alloy were safe. An output of 10 tons of anhydrous ammonia per twenty-four hours by the Claude process requires a supply of 1,200 kw. of electric energy, 1,000 kg. of steam per hour and 125 cu. metres of water per hour.

It should be noted that the Claude process of separating-out the hydrogen provided for extracting the benzol and the ethylene, and the values of these went towards paying for the cost of separating out the hydrogen. Nitrogen could be obtained by burning out oxygen from air with some of the hydrogen. Synthetic ammonia could be made by the original Haber-Rosignol process, as used in Germany; the modified Haber-Greenwood process, as used at Bellingham-on-Tees; the Claude process, as used in France and Belgium, or the Casali process, as used in Italy.

Claude and Casali processes were used in connection with many coke ovens on the Continent, etc., and it might well be asked why they were not used in this country. Perhaps one reason was that we had been making coke for a very long time.

One man in Lancashire who had inherited some beehive coke ovens would not hear of modifying the plant. He stated that the particular coke he was making was necessary for certain industries, and therefore an old-fashioned wasteful process was justified. People had no business to waste the assets in the coal. Only one man on a certain directorate knew anything about synthetic ammonia and the fact that he was pushing a proposal to make it, made him suspect by the others.

Since the Bellingham plant had been working, many references to it had appeared in the press; and the general public was beginning to know more about the importance of fixing nitrogen. He was glad that so large a plant had been erected at Bellingham, but it would not do to produce all our fixed nitrogen at one place. Apart from other considerations it was unsafe from the point of view of national safety.

In France synthetic ammonia was being made at several coke-oven plants, although there was also a large Government plant at Toulouse. That was the right policy.

M. J. E. OSTERRIETH (Belgium), in view of the coming competition between synthetic and by-product ammonia, emphasised the advantages of the former over the latter, these advantages having become manifest to him in the course of his experience in Belgium. For instance, he pointed out that synthetic ammonia was practically pure and that the sulphate of ammonia produced from it had only those impurities which occurred in sulphuric acid. This sulphate was snow-white and could be perfectly dried and neutralised, which enabled the sulphate to be stored in sacks without getting into lumps and without spoiling the sacks. This sulphate could be sold for exportation. On the contrary, sulphate of ammonia recovered from gas, especially that sulphate which was recovered by the direct process, contained traces of tar and other nitrogenous components,

such as pyridine. It also suffered from the disabilities of humidity and acidity. To be able to compete with synthetic sulphate, it would be necessary to dry and neutralise this sulphate. There was, however, no big difficulty in drying the sulphate; but the neutralisation was not easy, and this was a very important point, because of the hygroscopic properties of acid sulphate Experiments had been made on neutralisation with ammonia gas coming from synthetic plants, but without any definite success. The colour of the sulphate changed from white to light brown and pyridine was liberated, giving a disagreeable odour to the product. These facts would have to be considered in the choice of the ammonia recovery by-product plants.

Dr. Roy Illingworth (Great Britain) discussed a process, involving pre-heating of coal, for the production of a highly reactive coke, as an alternative to blending. The structure of coke, he said, arose from the breakdown of the β and γ compounds in the coal. Blending was really the choice of coals of different thermal stability, which, when mixed together, produced a one-stage coal. The structure of the coke from a one-stage coal was formed within very narrow limits of temperature, perhaps 50°C., at somewhere in the region of between 400° and 500°C. The natural one-stage coals gave a very highly reactive coke. In his process the coal was pre-heated at a temperature generally below 400°C. for quite a short time, in order to eliminate the less stable β and γ compounds, and the resulting product could then be carbonised in ordinary ovens at gasworks or coke ovens to produce a coke of certainly improved reactivity, as compared with that produced ordinarily. Also, the process allowed of rapid carbonisation, for tests had shown that as the result of pre-heating, about 30 per cent. of the time of carbonisation was saved. That saving was due to the fact that the product charged into the oven was drier than coal as usually charged. The production of a highly reactive coke which might be of value for ordinary domestic purposes could be obtained by blending as well as by pre-heating or by other methods, and the question as to which method should be adopted was purely one of economics. For instance, one might have two types of coal suitable for blending, within an economic range of one another as regards price; on the other hand, circumstances might be such that it would pay better to use the pre-heating process. Both blending and pre-heating, of course, added considerably to the cost, as compared with straight carbonisation, in which there were no intermediate stages. Finally, he said that we did not want empiricism in this matter. There were many different types of plant and many widths and heights of ovens, and in his experience he had found that the carbon-hydrogen ratio was the best basis of blending, because, as one was dealing then with fundamental principles, one could make allowances for variations in oven dimensions and need not carry out tests for each particular type of oven.

Mr. Norman E. Siderfin (Great Britain), dealing with domestic coke production, gave further information concerning experiments

carried out by the Gas Light and Coke Co. for the purpose of determining the effects of size of coal and of blending respectively upon the rate of carbonisation. The experiments Mr. Hollings had described in 1925, and which had been referred to by Dr. King in his paper (H7), had left the question as to the relative effects of these two factors rather obscure; and a third experiment, following the two already described, was carried out. In the first of the three experiments, ordinary Yorkshire coal was carbonised in vertical retorts at the Gas Light and Coke Co.'s works, and the throughput obtained was 4·8 tons per day. In the second experiment a blend was made of a Durham coal and a non-coking coal, with a view to minimising the plastic layer condition, *i.e.*, to make the fuel non-swelling. The maximum throughput obtained with that blend was $6\frac{1}{2}$ tons per day—an increase of from 35 to 40 per cent. He added that the blend was briquetted, but the briquettes broke down to some extent in handling, so that the net result was a semi-graded fuel, consisting of some whole briquettes and a great deal of fines. The third experiment, which had not been described previously, was made on a graded fuel. The Yorkshire coal as used in the first experiment was graded to a size above 1 in., all the fines being screened out. In the ordinary crushing operation, he pointed out, the softer coal was more or less automatically eliminated as fines, so that only the hard portions of the coal remained. Experiments had shown that in swelling properties this graded fuel was of about the same order as the briquettes in the previous experiment. Thus, the only difference between the second and third experiment was that in the latter the fuel was graded above 1-in. size. The throughput obtained with that graded fuel was as much as 8 tons per day—an increase of 70 per cent. over the throughput of 4·8 tons per day with the original coal. These results left one with the very definite impression that the rate of carbonisation was influenced in a much greater degree by the size of the fuel carbonised than by the blending. Experiments which were being made constantly on the experimental plant of the Company furnished data which supported that view; *e.g.*, when a "nutty" coal was being carbonised, the rate of gas evolution in the first two or three hours was certainly greater than when carbonising ordinary coal.

Dr. F. S. Sinnatt (Great Britain) pointed out that the remarks of Mr. Roberts and Dr. Illingworth indicated the need for some fundamental work on coal blending. He referred to an investigation he had carried out, largely with a view to distinguishing the wide variations in the properties of the different layers present in coal seams. In these experiments particles of coal of a critical size were carbonised at a temperature of above 550°C., and measurements were made of the bodies produced. The structure of these carbonised particles was found to be that of a hollow sphere built up of two main structures, having lattices with spaces covered by thin films which were called "windows." The windows varied in thickness and colour, and in some cases were brown, and in others

transparent to transmitted light. They had been called cenospheres. As a result of experiments carried out upon units of 2,000 particles, it had been found that the cenospheres produced from coal particles of the same size varied in volume from eleven times the size of the original particles to forty times the size. This result indicated that particles from the same layer in a coal seam (clarain) might vary in swelling properties, and in order to obtain the maximum value from such coal seams it was necessary for the various portions, the non-swelling and the swelling, to be intimately mixed. It would appear that there was some critical size to which coals from particular coal seams must be ground if coke of the maximum strength were to be obtained.

Dr. E. W. Smith (Joint Technical Secretary) said it seemed to him a great pity that it should have been accepted, in the discussions, that the 7 or 8 million tons of coke produced annually by one of the largest fuel industries in the country should not be satisfactory, and that the trend of the discussion should have been along the lines of special methods for blending and special methods for heat treatment prior to high-temperature carbonisation. It was well known that there was a definite demand for a domestic solid smokeless fuel in this country, but when we heard of gas coke and coke-oven coke taking the place of anthracite in America as a domestic fuel we wondered just how it would work here. It must be recognised that when speaking of a supply of domestic coke or domestic solid smokeless fuel in this country we had two things in mind; first that we required a free-burning solid smokeless fuel for the open grate, and secondly, a fuel for closed stoves, as, for instance, in central heating systems. The requirements for the open grate fuel were very different from those for the fuel used for central heating installations and central heating was very rapidly developing here. The fuel for central heating installations was similar to that used in America and on the Continent for closed stoves. It was unfortunate that when domestic central heating systems were installed in this country the boilers were invariably too small for burning coke or the special coalites, though they were satisfactory for burning anthracite and concentrated fuels of that type. Therefore, it was necessary to consider the improvement of the apparatus in which the material had to be used. He suggested it would have great influence if it were generally understood that this very responsible Conference would welcome the inauguration by the Institution of Gas Engineers of this gas country of a technical committee for the purpose of making a really thorough investigation into the present coke position. A big bulk of the coke supplied was already being used for domestic purposes with every satisfaction, subject to the stoves being large enough, but owing to quite a reasonable proportion of the coke supplied being quite unsatisfactory in some stoves, the market for the big bulk was being spoiled. He believed the trouble in the gas industry was largely the same as that in the coal industry.

There were 1 500 gas undertakings; a few of them were very large

ones and could afford to spend the necessary capital on investigations for improving the conditions, but there was a large number of others not large enough to handle the situation properly. Anything that could be done towards grouping the smaller undertakings would be valuable in the gas industry, just as the grouping of undertakings in the coking and coal industries would be of value there. Combination, amalgamation and organisation would assist very greatly. Such grouping would also help in the solution of the by-product ammonia problem. It might be a little injudicious, but he strongly believed that it would be a great deal better if there were large aggregations of gas undertakings in order that they could bring about concentration and deal with their ammonia properly instead of practically giving the material away, and it would help the economics of the industry as a whole. The question of hot liquor circulation for carbonising plants had been mentioned, and there was no doubt that from many points of view hot liquor circulation was a proved success. Many undertakings in the industry had adopted the closed circuit hot liquor circulation, and it had been found to be of great advantage. Finally, referring to Dr. Hohenhau's process for the utilisation of water as a fuel, he said he personally was completely ignorant of the work in question, and the World Power Conference would be very glad to receive at the earliest possible moment full data and statistics relating to the process. Some of them, including himself, who were very old-fashioned, believed that it had not yet been shown by any scientific method that energy could be created. Energy was present in one form or another and it was simply a matter of alteration of its form and so on. Water consisted of hydrogen and oxygen, and in order to split up that water, energy was required; and the energy available from the water in the form of hydrogen would be less than the energy necessary to split it up. No process was 100 per cent. efficient, and he made the statement definitely as a challenge—though he might be entirely wrong—that there could not be "creation" of energy. There might be an increase in efficiency.

MR. CHARLES COOPER (Great Britain), after expressing thanks for the manner in which his paper (H9) had been received, referred to the cost of gas drying. It was rather difficult, he said, to obtain figures showing the present cost to the gas undertakings of the maintenance of their distribution systems, and on that account it was not possible to obtain a definite figure representing the saving which could be made by de-hydrating the gas. There were a considerable number of plants working, however, and with all caution, he said it appeared to him that it was quite possible to save the cost of the de-hydration plant in five years.

DR. J. G. KING (Great Britain) (author of paper H7), replying to the discussion, agreed with Dr. Smith as to the necessity for studying the problem of grate manufacture. Gasworks coke had already a good market for certain types of heating, chiefly in closed stoves. If, however, the open grate could be made to burn gas coke as well as it could burn the low-temperature coke we were beginning to

hear so much of, he felt that the problem would be near a solution in that it would be attacked from both sides, namely, the production of a coke suitable for the present type of grate and the production of a grate suitable for gas coke. He had seen several grates of the latter type, and felt sure that before very long there would be quite a considerable increase in the amount of gas coke consumed in such grates. Referring to Mr. Roberts' remark that a horizontal retort was perhaps not suitable for making coke from blended coals, he said that the idea of carrying out the work in a horizontal retort was that it would bring out the differences in coals, these differences being fundamental to the coals and not to the retort. He supported Dr. Sinnatt's contention that further research was necessary in order to increase our knowledge of what happened when coals were blended and then carbonised. Dr. Illingworth had suggested that we could choose our coals according to Seyler's classification, but he (Dr. King) believed there was something more in it even than that. With regard to the volatile matter remaining in a smokeless fuel, he described one experiment which had been carried out in this connection. A smokeless fuel had been made at 600° C. and a portion of it subsequently re-heated in the absence of air to 900° C. to remove residual volatile matter. The first coke contained about 8 per cent. and the second about 1 per cent. of volatile matter. These fuels were then burned in an open grate under observation the component of horizontal radiation being taken as a measure of the relative amounts of heat given out. The re-heated coke ignited almost as easily as did the original coke, but burned more slowly and the fire lasted for a longer time. That again depended largely upon the type of grate used, and a slight modification in the design of the grate or the air supply might overcome any slowness.

Mr. P. Parrish (Great Britain) (author of paper H13), said that the object of his paper was not to create a discussion with regard to the merits of the direct or indirect processes for ammonium sulphate production. There was another object underlying it, and that was to urge the need for dealing with sulphate of ammonia on a proper scale, and to avoid the sale of it at unremunerative prices. Mr. Kilburn Scott, he said, was anxious to use the hydrogen of coke-oven gas for the production of synthetic ammonia. Why had he not directed attention to the utilisation of the ammonia which was already available at a price of only £3 18s. per ton? That was a problem which the by-product industries, both the coke-oven industry and the gas industry, had to solve, and it was capable of solution. The trouble was that the treatment of gas liquor or ammoniacal intermediates had not been undertaken on a large scale. If the by-product industries were to realise for ammonia what it really merited, there must be centralisation of works and the development of mass production.

On the motion of Dr. E. W. Smith, a hearty vote of thanks was accorded to Mr. John Terrace for his conduct of the meeting.

SECTION J

UTILISATION OF FUELS FOR STEAM GENERATION AND THE PRODUCTION OF ELECTRICITY

THE NUMBERS ARE THOSE GIVEN TO EACH PAPER FOR USE AT THE FUEL CONFERENCE

DIE ENTWICKLUNG DER FEUERUNGSANLAGEN DER WIENER STÄDTISCHEN ELEKTRIZITÄTSWERKE

(DEVELOPMENT OF FUELLING ARRANGEMENTS AT THE VIENNA MUNICIPAL ELECTRICITY WORKS)

AUSTRIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

ING. FRITZ SIEDLE

Paper No. J1

CONTENTS

EINLEITUNG.—Der Zerfall der Österr. Ungar. Monarchie nach dem Weltkriege hatte unter anderem zur Folge, dass der grösste Teil der ehemaligen inländischen Kohlenreviere an das Ausland überging, wodurch auch die Deckung der für den Betrieb der Wiener st. Elektr. Werke notwendigen Kohlen in einschneidender Weise erschwert wurde. Ihre Feuerungsanlagen waren seit Errichtung des eigenen Kraftwerkes in Simmering für die Verheizung von nur guten Stein- und Braunkohlen eingerichtet und, da sich das neue Ausland hermetisch gegen Österreich absperrte, nach dem Zusammenbruch mit einem Schlage beinahe vollständig von dem Bezuge derselben abgeschnitten. Es war somit ein Gebot der Selbsterhaltung, aus dieser schwierigen Situation herauszukommen. Dies war nur durch den seither auch erfolgten Ausbau von Wasserkräften, die Ausgestaltung des mit Lignit aus werkseigenen Gruben beheizten Kraftwerkes in Ebenfurth und im übrigen nur auf dem Wege der Umgestaltung der Dampfkesselfeuerungen für die Verheizung von inländischen minderwertigen Stein- und Braunkohlen möglich.

Diese Umstellung, welche sofort in Angriff genommen wurde, wird die St. E.W. vom Bezuge ausländischer Kohlen gänzlich unabhängig machen. Die bezüglichen Arbeiten waren durch die Notwendigkeit der Aufrechterhaltung der seit Kriegsende in ungeahnter Weise steigenden Stromerzeugung sehr behindert und erschwert. Sie sind jedoch für die St. E.W. wie auch für die österreichische Volkswirtschaft von solcher Bedeutung, dass im folgenden die Durchführung dieser Umbauten beschrieben werden soll.

Bei Betriebsaufnahme der St. E.W. im Jahre 1902 stand nur das eigene Kraftwerk Simmering zur Verfügung. Seine Babcock-Wilcox-Dampfkessel mit je 300 m² Heizfläche waren ursprünglich mit Planrosten von je 8,0 m² Rostfläche versehen. Entsprechend dem damaligen Stande der Heiztechnik betrug der Anstrengungsgrad dieser Feuerungen ca. 500 000 W.E. pro m² Rostfläche und Stunde bei Verwendung von Förder-Steinkohlen mit einem oberen Heizwert von 6 600 kcal, 8% Feuchtigkeit und 12% Asche aus den Oberschlesischen und Ostrauer-Karwiner Revieren. Die Bedienung der Planroste erfolgte von Hand aus, indem der Brennstoff aus den vor den Kesseln stehenden Kohlenwagen durch die Feuertüren auf den Rost aufgeworfen wurde. Wie damals gebräuchlich, erfolgte die Abschlackung ebenfalls von Hand durch die Feuertüre.

Das Bild (1) zeigt einen Vertikalschnitt durch diese Planrostfeuerung.

Das Bild (2) einen Blick in eines der beiden Kesselhäuser in den ersten Betriebsjahren.

Mit der raschen Zunahme der Stromerzeugung in den folgenden Jahren und der damit erforderlichen Verfeuerung immer grösserer Kohlenmengen, gestaltete sich diese Art der Feuerbedienung und Zubringung zu den Kesseln immer schwieriger, sodass die St.E.W. bereits im Jahre 1906 den Umbau der Feuerungen mit Verwendung von Kettenrosten, wie sie damals von den englischen Babcock-Wilcox-Werken gebaut wurden, in Angriff nahmen, wobei gleichzeitig auch die Zubringung der Kohle zu diesen neuen Kettenrostfeuerungen auf mechanischem Wege mittels einer Konveyoranlage bewerkstelligt wurde. Die Durchführung dieser Umgestaltungen war im Jahre 1912 bei allen damals vorhandenen 68 Dampfkesseln vollendet, sodass seit dieser Zeit ausschliesslich Kettenrostfeuerungen mit verschieden grossen Rostflächen und für natürlichen Zug in Verwendung standen. In der Nachkriegszeit wurden, da Kohle nicht ausreichend erhältlich war, aushilfsweise auch 12 Dampfkessel mit Rohöl geheizt, zu welchem Zwecke die Kettenroste entfernt und die so erhaltenen Feuerräume mit je 3 Ölbrennern

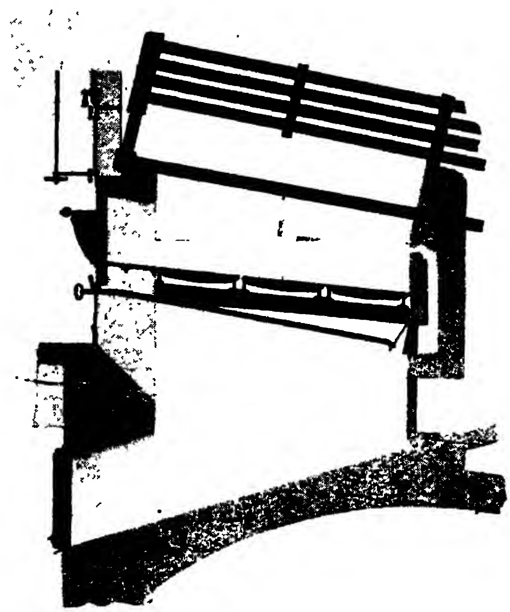


Abb. 1. Vertikalschnitt durch die Planrostfeuerung des Kraftwerkes Simmering, 1902.

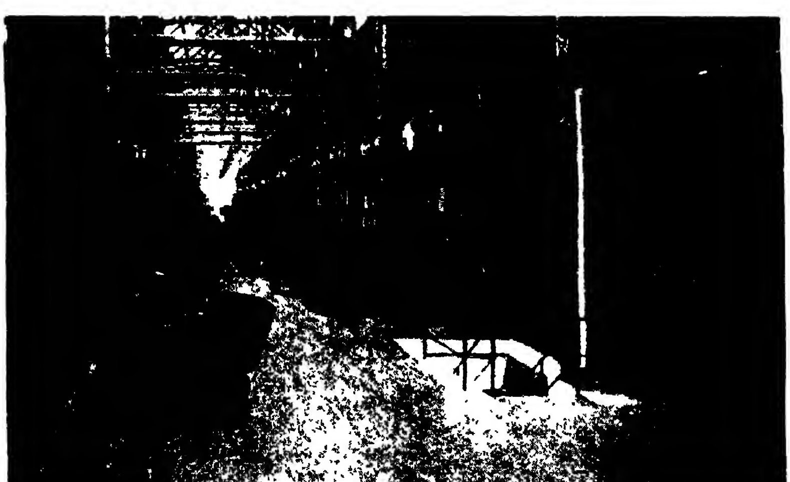


Abb. 2. Blick ins Kesselhaus des Kraftwerkes Simmering aus den ersten Betriebsjahren.

versehen wurden. Für die übrige Anlage standen damals fast nur Kohlen minderer Qualität zur Verfügung, welche sich zur Verheizung in den bestehenden Kettenrostfeuerungen schlecht eigneten. Es war deshalb während dieser Zeit nicht möglich, den vollen Strombedarf zu decken, weshalb der Licht- und Kraftkonsum in empfindlicher Weise eingeschränkt werden musste. Erst im Jahre 1923 begannen die Verhältnisse auf dem Kohlenmarkte wieder besser zu werden, sodass die Ölfeuerung entfernt und die früher verwendeten Kettenroste wieder in Benützung genommen werden konnten. Ausserdem war es nunmehr möglich, bei der im Jahre 1925 notwendig gewordenen Erweiterung der Kesselanlage die Kettenrostfeuerungen neuerlich anzuwenden.

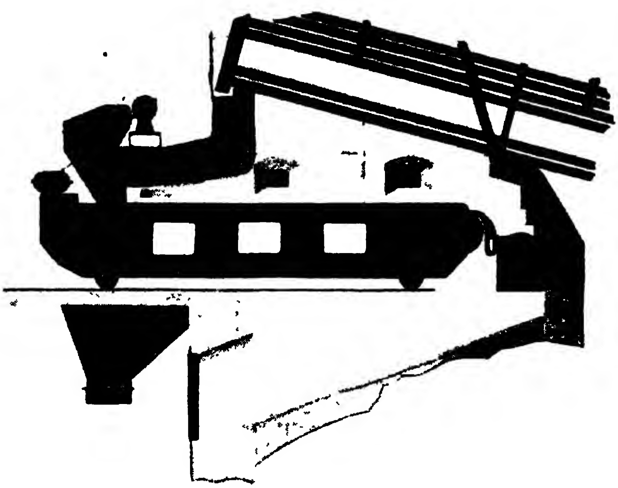


Abb. 3. Schnitt durch die Kettenrostfeuerung des Kraftwerkes Simmering, 1912.

Aus dem Bilde (3) ist die Ausführung der Kettenrostfeuerung bei den alten Kesseln von 300 bis 500 m² Heizfläche nach dem Umbau derselben zu ersehen.

Das nächste Bild (4) zeigt die Anwendung einer Wanderrostfeuerung bei einem der im Jahre 1925 aufgestellten Kessel von 500 m² Heizfläche. Beim Vergleich beider Anordnungen tritt der Unterschied der Feuerräume besonders hervor. Wie anderwärts hat auch bei uns die Erfahrung gezeigt, dass zur vollkommenen Verbrennung und zur Erzielung einer praktischen Rauchfreiheit die Feuerräume weit höher zu wählen sind, als es in der Vorkriegszeit

noch üblich war. Durch die neue Anordnung konnte die Rostleistung auf 700 000 W.E. pro m² Rostfläche und Stunde sowie der Kesselwirkungsgrad im Betriebe auf 78% erhöht werden.

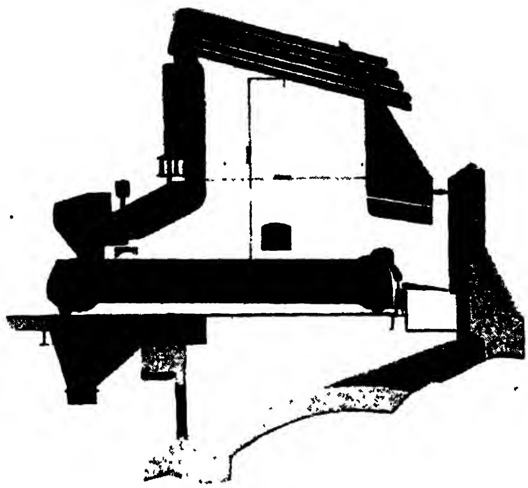


Abb 4. Schnitt durch die Wanderrostfeuerung des Kraftwerkes Simmering, 1925.

Im nächsten Bilde (5) wird ein Blick in das gleiche Kesselhaus nach dem Stande Ende 1925 gezeigt.

Übernahme der drei privaten Elektrizitätswerke.—In den Jahren 1907, 1908 und 1914 wurden die damals bestehenden 3 privaten Elektrizitätswerke und zwar die Wiener Elektrizitäts-Gesellschaft mit dem kalorischen Kraftwerke Kaunitzgasse, die Internationale Elektrizitäts-Gesellschaft mit dem Kraftwerke Engerthstrasse und die Allgemeine Österreichische Elektrizitäts-Gesellschaft mit den Kraftwerken Obere Donaustrasse und Neubadgasse von der Gemeinde Wien käuflich übernommen. Die Feuerungsanlagen in diesen Kraftwerken bestanden ebenfalls aus Planrosten für Handbeschickung, ähnlich wie die ursprüngliche Einrichtung für das eigene Kraftwerk Simmering. Von diesen Kraftwerksbetrieben wurde jedoch nur jenes in der Engerthstrasse weitergeführt und die übrigen teilweise zu Unterwerken umgestaltet und teils anderen Zwecken zugeführt.

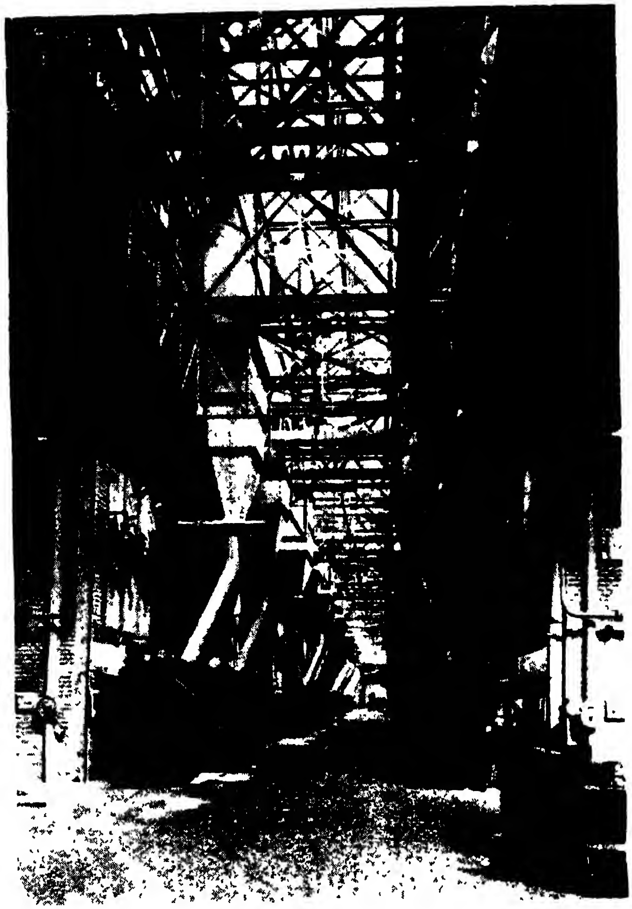


Abb. 5. Blick ins Kesselhaus des Kraftwerkes Simmering nach vollendetem Umbau sämtlicher Feuerungen

Kraftwerk Engerthstrasse.—Nach der Übernahme des Kraftwerkes Engerthstrasse wurde damit begonnen, die bestehenden Planrost-Feuerungsanlagen gegen solche mit Kettenrosten auszuwechseln, sodass die alten Kessel dieses Kraftwerkes vor dem Beginne des Weltkrieges ausschliesslich Feuerungen besassen, welche sich so wie im Kraftwerk Simmering vorwiegend für die Verwendung von nur guten Stein- und Braunkohlen eigneten. Jene Kessel, welche infolge ihres Alters ihren Umbau unwirtschaftlich erscheinen liessen, wurden gegen grössere Steilrohrkessel mit mechanischen Pluto-Stokern ausgewechselt, welche sich auf Grund der gemachten Erfahrungen fur die Verheizung von inländischen Kohlen mittlerer Qualitat am besten eigneten.

Im Bild (6) ist ein Vertikalschnitt durch die Pluto-Stoker-Unterwindfeuerung mit 22 m² Rostfläche zu sehen. Dieselbe besteht aus einer Anzahl ca. 3 m langer Hohlroststäbe, an welche ca. 1,2 m lange einfache Roststäbe angehängt sind. Die Roststäbe sind nach rückwärts um ca. 22° gegen die Horizontale geneigt und werden abwechselnd nach vorne und rückwärts bewegt, sodass durch die

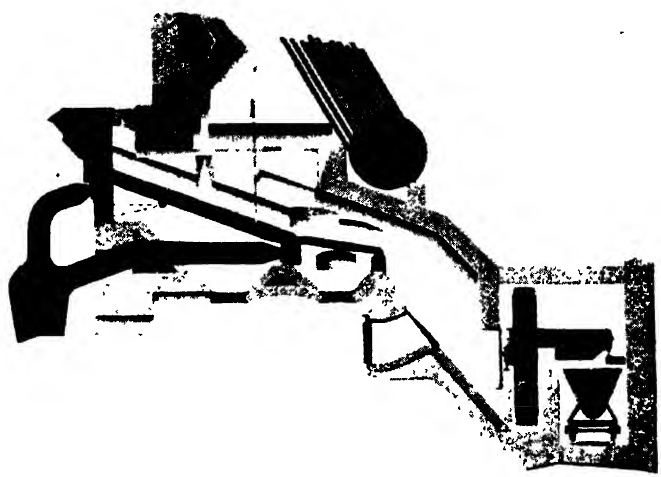


Abb. 6. Pluto-Stoker-Unterwindfeuerung der Kraftwerke Engerthstrasse und Ebenfurth, 1922.

Gegenbewegung zweier benachbarter Roststäbe die vom Kohlenvorschub aufgeförderte Kohle langsam nach dem Rostende wandert.

Die Verbrennungsluft wird durch einen Ventilator zum grössten Teile von vorne dem Hohlraum der Roststäbe zugeführt, von wo die Luft durch auf der Brennbahn derselben vorgesehene Schlitze in den Feuerraum eintritt. Die zur Verheizung gelangenden inländischen Stein- und Braunkohlen besitzen 12 bis 25% Feuchtigkeit, sind zumeist aschenreich, oft schwer brennbar und neigen teilweise zum Backen, sodass zum Ausbrennen auf dem Anhängerost fallweise weitere Verbrennungsluft zugeführt werden muss. Diesen Brennstoffeigenschaften trägt auch die Anordnung der Feuergewölbe Rechnung. Zum rechtzeitigen Zünden ist das rückwärtige Gewölbe soweit nach vorne gezogen, dass die Feuerhitze gegen die Kesselheizfläche noch gut ausstrahlen kann. Hiebei ist bemerkenswert, dass die Ausbringung der Schlacke aus diesen Feuerungen unter vollkommenem Wasserabschluss auf mechanischem Wege erfolgt. Zu diesem Zwecke ist am Rostende ein Wassertrog

vorgesehen, in welchem ein wasserradartiges Schöpfrad eintaucht, welches die gelöschte Schlacke ausschöpft und in die bereitstehenden Wagen entleert.

Die Umänderung sämtlicher Kessel im Kraftwerk Engerthstrasse auf diese Feuerung war im Jahre 1925 vollendet und erfolgt seit dieser Zeit die Stromerzeugung dieses Betriebes vollständig aus inländischen Brennstoffen. Nunmehr erst konnte der Umbau im Kraftwerk Simmering in Angriff genommen werden, denn eine gleichzeitige Umgestaltung beider Kraftwerke war wegen der ungestörten Aufrechterhaltung der Stromversorgung nicht möglich.

Überlandkraftwerk Ebenfurth.—Im Jahre 1914 wurde 40 km südlich von Wien das Überlandkraftwerk Ebenfurth zum Zwecke der Ausnützung der in unmittelbarer Nähe befindlichen Zillingdorfer Lignitkohlenlager errichtet. Bei den dortigen Kesselfeuerungen stehen mechanische Pluto-Stoker in ähnlicher Ausführung wie jene im Kraftwerk Engerthstrasse und automatische Treppenroste, Patent Schnetzer, in Verwendung. Anfänglich haben sich infolge der Eigenschaften der Lignitkohle Schwierigkeiten herausgestellt, die hauptsächlich auf eine unerprobte Gewölbeanordnung und Luftführung zur Feuerung zurückzuführen waren. Es hat sich gezeigt, dass die Zillingdorfer Lignitkohle, welche etwa einen oberen Heizwert von 2 200 W.E. bei 45% Feuchtigkeit und 25% Asche besitzt, für das rechtzeitige Anbrennen und vollständige Ausbrennen grössere Rostlängen und noch weiter nach vorne gezogene und besonders ausgebildete Zündgewölbe verlangt, als dies bei jenen im Kraftwerk Engerthstrasse für höherwertige Inlandskohlen in Verwendung stehenden gleichartigen Feuerungen notwendig ist.

Beide Rosttypen, deren Rostflächen ungefähr 24-28 m² besitzen, bestehen aus 3-4 m langen gegen die Horizontale in 24° geneigten Brennbahnen, durch welche der Unterwind dem Feuer zugeführt wird.

Es hat sich nun weiter ergeben, dass der kalte Unterwind für das erste Drittel des Rostes keine günstige Wirkung auf die feuchte Rohkohle ausübt und das Anbrennen derselben verzögert. Ausserdem hat sich mit Rücksicht auf das vollständige Ausbrennen eine grössere Länge der eigentlichen Brennzone und des Anhängerostes als notwendig erwiesen. Es musste somit darnach gestrebt werden, die sich scheinbar widersprechenden Forderungen durch Änderung der Rost-Konstruktion und der Feuerung bezw. durch die Verwendung von vorgewärmter Verbrennungsluft einer entsprechenden Lösung zuzuführen.

Aus diesem Grunde wurden vor etwa 2 Jahren beide Methoden bei je einem der Kessel des Überlandkraftwerkes einer Erprobung unterzogen. Zu diesem Behufe wurde an einem Pluto-Stoker eine Konstruktionsänderung vorgenommen, durch welche trotz der Vergrösserung der totalen Rostfläche von 26 auf 32 m^2, eine Gewichtsersparnis von ca. 20 % und eine Steigerung der spezifischen Dampfleistung pro m^2 Heizfläche und Stunde um 50% erzielt wurde. Hiebei konnten 350 kg Lignitkohle pro m^2 Rostfläche und Stunde bei einer Höhe der Kohlenschichte über dem Roste von ca. 70 cm verheizt werden. Es ist deshalb beabsichtigt, auch die übrigen älteren Pluto-Stoker nach und nach auf die neuere Konstruktion umzuändern.

Abb. 7. Spezialausführung dieses Pluto-Stoker für das Überlandkraftwerk Ebenfurth in der Montagewerkstätte der Lieferfirma.

Aus dem Bilde (7) ist diese Konstruktion, in der Werkstätte der Lieferfirma zusammengebaut, zu ersehen.

Der Aufbau der Feuerung ist aus dem Bilde (8) zu entnehmen. Beim Vergleich derselben mit der ursprünglichen Ausführungsweise nach dem Bilde (6) ist zu bemerken, dass die teueren Hohlroste um die Schwelzone gekürzt und deren Länge nur auf die eigentliche Brennbahn beschränkt ist. Der Unterwind tritt deshalb nur dort in die Feuerung ein, wo die Luft zur Verbrennung erforderlich ist.

Dieser geänderte Pluto-Stoker zerfällt in 3 zusammenhängende Teile, den Schwelrost, den Hohlrost und den Anhängerost. Der Unterwind wird dem Hohlrost durch den hinteren Rostbalken zugeführt, der Schwelrost ist bis zu den Rostköpfen mit Schamotteplatten abgedeckt und es kann durch die letzteren sowie auch zum Anhängerost, im Bedarfsfalle durch die Betätigung von Klappen, Unterwind zugeführt werden. Ausserdem ist eine wesentliche Vergrösserung des Feuerraumes zu erkennen.

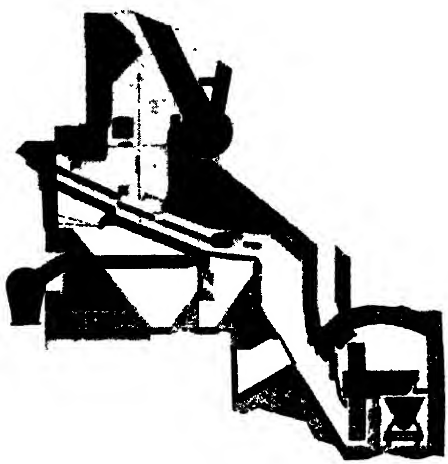


Abb. 8. Schnitt durch die Spezial-Pluto-Stoker-Feuerung des Überlandkraftwerkes Ebenfurth 1926.

Die andere Methode zur Erzielung einer höheren Rostleistung durch vorgewärmte Verbrennungsluft wurde bei einer Schnetzerrostfeuerung angewendet. Zu diesem Zwecke wurde in dem Rauchgasstrom hinter dem Ekonomiser ein Luftvorwärmer, Patent Ljungström, eingebaut, durch den der Unterwindventilator die auf ca. 100-120°C erwärmte Verbrennungsluft ansaugt. Hiedurch wird ebenfalls ein rascheres Anbrennen der feuchten Rohkohle erreicht, sodass die Rostleistung im ungefähr gleichen Ausmasse gesteigert wurde, wie dies bei der geänderten Pluto-Stoker-Konstruktion ohne vorgewärmte Verbrennungsluft erzielt wurde. Die Anlagekosten bei Verwendung von Luftvorwärmern stellen sich zwar höher; trotzdem machen sich diese Mehrkosten sehr bald durch die obigen Vorteile bezahlt, insbesonders dann, wenn es möglich ist, diese Luftvorwärmung noch zu erhöhen. Dahin abgerichtete Versuche bei der geänderten Pluto-Stoker-Feuerung sind bereits im Gange.

Die Verheizung der Lignitkohle stellt noch grössere Anforderungen an die Wegbringung der Schlacke und Asche als dies in dem Wiener Kraftwerke Engerthstrasse der Fall ist. Bisher wurde auch im Überlandkraftwerk die Schlacke noch von Hand in Wagen abgezogen und mittels Lokomotiven abtransportiert. Die Umgestaltung der Abschlackung in ähnlicher Weise wie im Kraftwerk Engerthstrasse ist jedoch bereits im Zuge. Die Anordnung derselben ist ebenfalls aus dem Bilde (8) zu ersehen.

Abb. 9. Blick in das Kesselhaus des Überlandkraftwerkes Ebenfurth.

Das Bild (9) zeigt einen Blick ins Kesselhaus; im Vordergrund treten besonders die reichlichen Dimensionen der Fallrohre zwischen Kohlenbunker und Rost hervor.

Kraftwerk Simmering, Kohlenstaubfeuerung.—Im Jahre 1926 wurde anlässlich des Ersatzes von alten unbrauchbar gewordenen Betriebsmitteln mit dem Umbau der Betriebsanlagen im Kraftwerk Simmering begonnen. Während die alte Kesselanlage für einen Dampfdruck von 14 atü und 300°C Dampftemperatur gebaut ist, wurde bei der Ersatzanlage in Wahrnehmung der Vorteile, welche in der Verwendung von hochgespanntem und hochüberhitztem Dampf und der sonstigen inzwischen hervorgetretenen Errungenschaften auf dem Gebiete der Dampftechnik für den Elektrizitätswerksbetrieb liegen, die Verwendung von Dampf mit 35 atü und 420°C Dampftemperatur am Austritt des Kessels in Aussicht genommen. Auf Grund der damals vorliegenden Erfahrungen über die Kohlenstaubfeuerung und der eigenen mit inländischen Kohlen durchgeführten Heizversuche in solchen, wurde die Anwendung der Kohlenstaubfeuerung bei den neuen Kesseln beschlossen. Hiezu trug der Umstand besonders bei, dass diese inländischen Förderkohlen bei der bisherigen Verheizung auf dem Pluto-Stoker- und Kettenrost keine so hohe Ökonomie ergeben haben, wie sie bei den Heizversuchen in den Kohlenstaubfeuerungen erzielt wurden.

Der erste Ausbau dieser neuen Kesselanlage besteht aus 4 Hochdruck-Dampfkesseln von je 1 150 m² wasserberührter Heizfläche zum Betriebe zweier Dreizylinder-Dampfturbinen mit zusammen 60 000 PS maximaler Dauerleistung. Im Rauchgasstrom dieser Kessel sind gusseiserne Rippenrohrvorwärmer von durchschnittlich 700 m² und Luftvorwärmer von je 1 000 m² eingeschaltet. Jeder Kessel besitzt 40 t/h Dampf Normal- und 50 t/h Dampf Maximal-Dauerleistung und ist mit einer Kohlenstaubfeuerung versehen, deren Seitenwände keine Kühlrohre aufweisen und aus welcher die Schlacke in flüssiger Form aus dem Feuerraum in einen Wassersumpf tropft, dort granuliert und mittels Greiferlaufkatze in die bereitstehenden Schlackenwagen gefördert wird.

Die Ausführung der Kohlenstaubfeuerung ist aus dem Bilde (10) zu ersehen und der Rauminhalt derselben beträgt rund 202 m³. Bei den zur Verwendung gelangenden inländischen Kohlen mit einem mittleren Heizwert von ungefähr 4 500-5 500 W.E. pro kg Trokkenkohlenstaubes, errechnet sich die normale Beanspruchung des Feuerraumes auf etwa 150 000 und maximal auf ca. 190 000 W.E. pro m³ Feuerraum und Stunde.

Der Schmelzpunkt der aus diesen Brennstoffen anfallenden Schlacke liegt ungefähr bei 1 000°C und wurde die Ausbringung der Schlacke in flüssiger Form in einigen damals schon bestehenden

fremden Kohlenstaubfeuerungen ausprobiert. Ausserdem hat es sich inzwischen in neuen in gleicher Weise ausgeführten Kesselanlagen erwiesen, dass diese Art der Ausbringung der Schlacke bei richtiger Feuer- und Flammenführung anstandslos erfolgt, ohne das feuerfeste Mauerwerk zu zerstören.

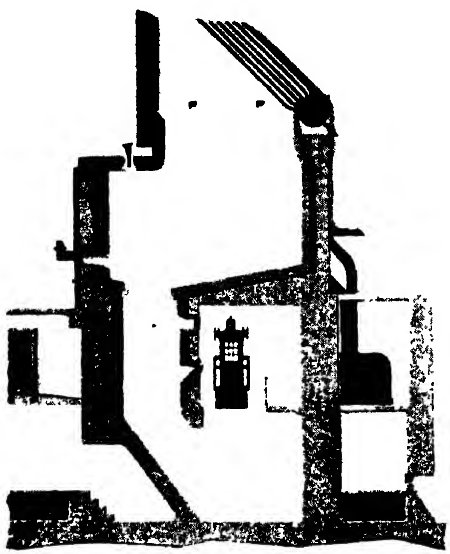


Abb. 10. Schnitt durch die Kohlenstaubfeuerung des Kraftwerkes Simmering, 1928.

Die Weglassung des Wasserrohrschutzes und des Granulierrostes hat einen einfachen Aufbau der Feuerung und des Kessels gestattet. Die aus hochfeuerfestem Material hergestellten Wände besitzen jedoch einen Kühlmantel, durch welchen die Sekundärluft, bevor sie in die Feuerung gelangt, hindurchgepresst wird. Der Kohlenstaub wird durch je 3 Stück schnellaufende Schlagkreuz-Doppelmühlen mit je 3 t stündlicher Leistung und einer Feinheit von 25% Rückstand auf dem 4 900-Maschensieb direkt den Brennern der Feuerung zugeführt. Es findet somit keine Bunkerung von getrocknetem Kohlenstaub statt.

Die Rohkohle wird in 4 Trommeltrocknern, deren jeder 9 000 kg Nasskohle um 10% Feuchte mittels Rauchgasen von 260-300°C, welche aus den Kesseln hinter den Ekonomisern abgesaugt werden, abzutrocknen imstande ist, getrocknet.

Erfolg der Um- und Neubauten.—Nach Inbetriebnahme dieser Neuanlage Mitte 1928 wird praktisch die Unabhängigkeit der Wiener Kraftwerke vom Bezuge ausländischer Kohle erreicht sein.

RÉSUMÉ

The above statement shows to what extent the Municipal Electricity Works have succeeded in accommodating the furnace installations of their steam power plant to meet actual requirements, from the date of their erection up to the year 1928, placing them upon a level of the highest possible economy and service efficiency in keeping with the technical progress bearing on matters of furnace construction.

It need hardly be emphasised that this gradual development suffered an interruption through the outbreak of the Great War, considering that in the pre-war period with a regular and well assured supply of fuel, and a first-class supply at that, this development went on smoothly, tending in the main to an increase in economy in point of work and the specific rate of combustion. With this object in view the Vienna power works of Simmering and Engerthstrasse replaced the flat grates employed since the erection of these works by mechanical chain grates, enlarging at the same time the furnace premises, and adapting coal feeding devices to the mechanical operation of the plant.

At the close of the war, however, the hitherto available coal-producing territories became foreign property, thus almost entirely checking the supply of first-class material, and creating the urgent necessity for re-modelling the furnace plants of the two Vienna power stations of Simmering and Engerthstrasse for the consumption of native coal, presenting a drawback in point of quality mainly owing to its high percentage of ash and water. For this reason, the utilisation of this material yielded only extremely poor results on combustion, proving entirely inadequate for the normal current supply; although the situation was considerably relieved by the long distance power station, Ebenfurth, completed shortly prior to the outbreak of the war, when operating with lignite extracted from its own mines Therefore, the Municipal Electricity Works found themselves at the afore-mentioned period in a bad plight, demanding extreme measures for economising the available current. To bridge over this crisis new waterways were carried out, the Ebenfurth power-station was enlarged, and the chain grate furnaces of the Engerthstrasse power-station were replaced by Pluto-stoker furnaces of a construction similar to those in the Ebenfurth power-station Pulverised coal-fired systems were also introduced at the Simmering power-station in conjunction with a high-pressure steam installation

The difficulties resulting, in the beginning, from the combustion of native fuel material were overcome by a suitable re-arrangement of the grate construction as well as that of the combustion chamber and ashpit.

The re-modelling of the existing furnace installations and the establishment of coal dust firing is described in the statement by means of diagrams and technical particulars

RESEARCHES WITH HIGH-PRESSURE STEAM

CZECHOSLOVAKIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

DR. JAROSLAV HAVLÍČEK

Paper No. J2

CONTENTS

In the year 1924 the erection of a high-pressure plant to operate at about 110 atmospheres and the greatest possible degree of superheating was planned in Czechoslovakia. The progress of the preliminary work showed difficulties in the design of the boilers and the turbine, owing to the fact that the physical qualities of high-pressure steam were not sufficiently explored. Entropy tables for pressures of more than 40 atm. abs. were at this time unknown. The entropy tables by Stodola from 1924 and by Mollier from 1925, which, a few measured values excepted, are chiefly based on extrapolation and the knowledge of the laws of heat-theory, only appeared later. It was, therefore, a matter of the utmost urgency to develop an entropy table on the basis of actual measurements. The author had already proposed at the meeting of the fourth Department of the Masaryk Academy of Work (Masarykova Akademie Práce—M.A.P.) of November 29, 1923, that this department in collaboration with the Technical University of Prague should set up a testing plant, where the heat contents of high-pressure steam up to above the critical pressure and up to 500°C. should be measured. On the basis of these measurements an entropy diagram was then to be made out.

At the next meeting of the M.A.P. on February 26, 1924, this suggestion and the first design of the measuring equipment were thoroughly discussed and approved. For its realisation a Commission was formed, the members being:

Chairman: Ing. J. Zvoníček, Professor of the Technical University of Prague.

Research Director: Ing. phil. Dr. J. Havlíček, Chief Mechanical Engineer of the Vitkovice Coal Mines at Mor. Ostrava.

Other Members: Ing. V. Krouza, Professor of the Technical University of Prague,

Ing. J. Kieswetter, Managing Director of the Skoda Works at Plzeň.

The Commission, in the work of which Prof. Zvoníček took a large

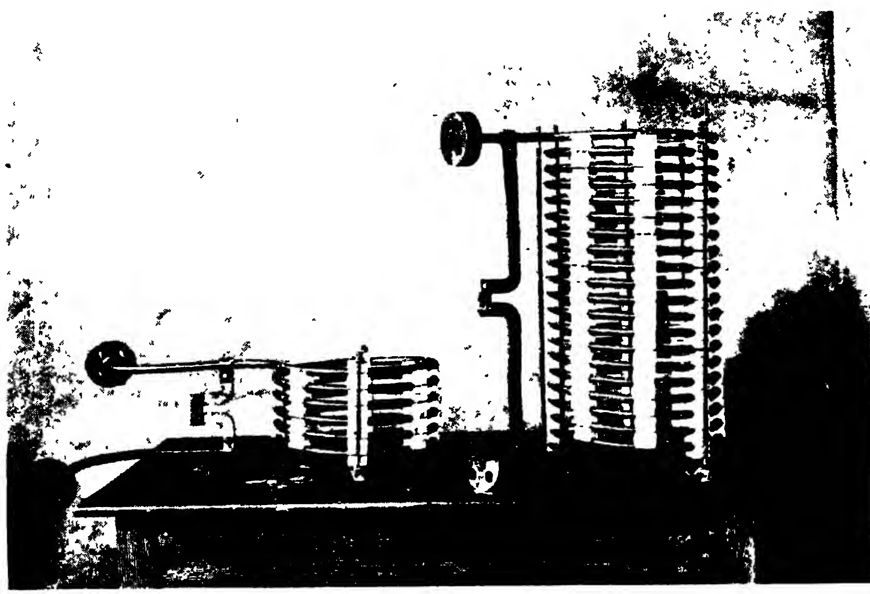


Fig. 1.

part up to his death, designed a test plant with the following characteristics:

1. The heating surface of the boiler is composed of steel tubes, heated as short-circuited secondary coils of an A.C. transformer by the current flowing therein (Fig. 1). The energy used for heating is measured by a wattmeter, influenced by the current flowing in the secondary coil and by a voltage coil running parallel with the secondary coils. The energy of hysteresis and eddy currents which cannot be ascertained by this method is measured by open secondary circuit and with various magnetisations. The heating is regulated by gradually connecting or disconnecting primary windings, applied to a current source with constant voltage.

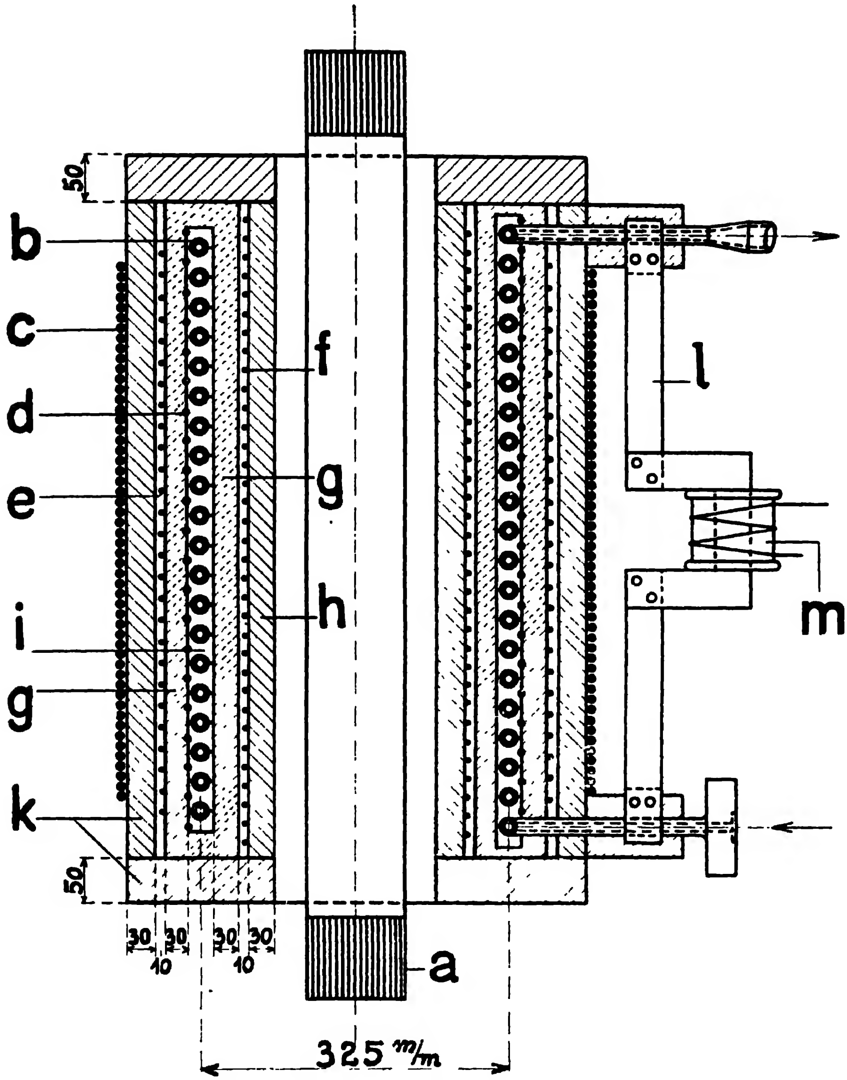


Fig. 2.

a Transformer core.
b Pipes of the boiler, secondary coil of the transformer.
c Primary coil of the transformer.
d Voltage measuring coil.
e Exterior heating resistance.
f Interior heating resistance.
g Glass wool insulation.
h Thermalite insulation.
i Distance pieces of clay.
k Thermalite insulation.
l Short connection of the secondary coil
m Current transformer.

2. In measurements of the heat of evaporation up to the critical pressure the heating coils of the boiler are connected to a tank in such a way that the circulation of the water takes place through the

heating coils and the tank situated above them. This tank was not employed in former tests. It is supposed to serve for the measurement of the latent heat of evaporation and the boiling temperature up to the critical pressure.

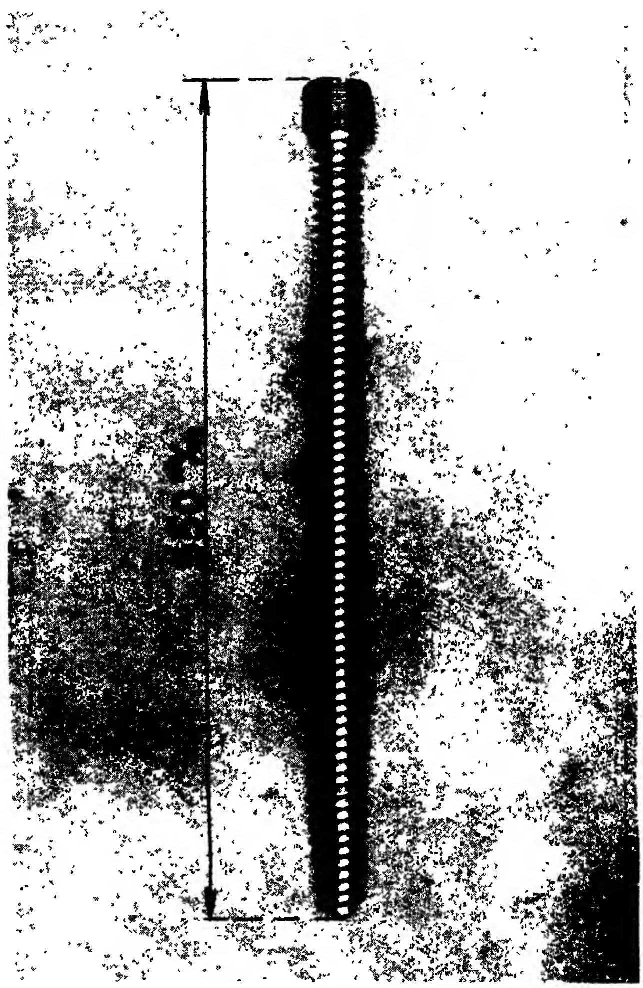


Fig. 3.

3. The heating coils are insulated by a coat of glass wool, 30 mm. thick. At both sides of this insulation several bifiliary spirals of plain resistance wire (Cekas wire) are wound, which, according to requirements, can be connected or disconnected. The electrical energy passing through them is measured and serves to cover the loss of heat through conduction. These heat windings are insulated

by a thermalite stone cover; every stone is 30 mm. thick. In addition, the whole insulated winding is closed at top and bottom with covers of thermalite stones, 50 mm. thick. Over the outer shell of thermalite stones the primary coil of the transformer, made of copper wire, insulated with asbestos, is wound. The disposition is shown on Fig. 2. In the air gap between the glass-wool insulation and the thermalite-stone insulation, which is about 10 mm. wide and which contains the heating wires mentioned above, thermo elements made of iron-constantan are enclosed at several points, by means of which the temperature in this air space is measured. This temperature is maintained at the level of the temperature in the heating coils of the boiler, which is also measured by iron-constantan thermo-elements, so that as far as possible all losses of heat are covered by the heating equipment and so that the electrical energy in the heating coils of the boiler for heating, evaporating and super-heating of the water and the steam can be completely utilised.

4. The steam to be measured is led behind the heating coils to a measuring case, where a tube for the mercury thermometer and thermo-element is immersed. This tube has screw-shaped ribs (Fig. 3), to effect a good transmission of heat from the surrounding steam and the thermometers inserted in the pipe. Behind the measuring case a throttle valve is built in, to throttle the steam from high-pressure to about 1·2 atm. absolute. The throttle valve is a most exactly-fitting well-polished cone with labyrinth grooves. After the throttle valve a measuring case provided with a thermometer of the same design as used in the high-pressure part is incorporated.

5. From the measuring pipe the steam flows to a condenser, where the steam is condensed. Moreover the quantity of cooling water is measured by a calibrated tank and the temperature-increase in the condenser by mercury thermometers. The condensate obtained is weighed.

6. A reciprocating feed pump continually forces the feed water into the tube coil. The equipment used in the last measurements (without the tank at the boiler and the supplementary superheater after the boiler) may be seen in Figs. 4, 5 and 6.

The effect of the transformer of the boiler in the secondary part is about 12 kW., so that the quantity of steam produced, measured at a temperature of 310°C. amounts to about 16 Kg. per hour and about 12·5 Kg. per hour when measured at a temperature of 500°C.

With this equipment the heat content of the water as well as of the steam could be measured.

The equipment was built partly at the expense of the M.A.P., partly by subsidies from the Ministry for Public Works, and to a great extent by donations from the Czechoslovakian industry, which supplied the various parts of the plant gratis.

After the death of Prof. Zvoníček it was decided that the test

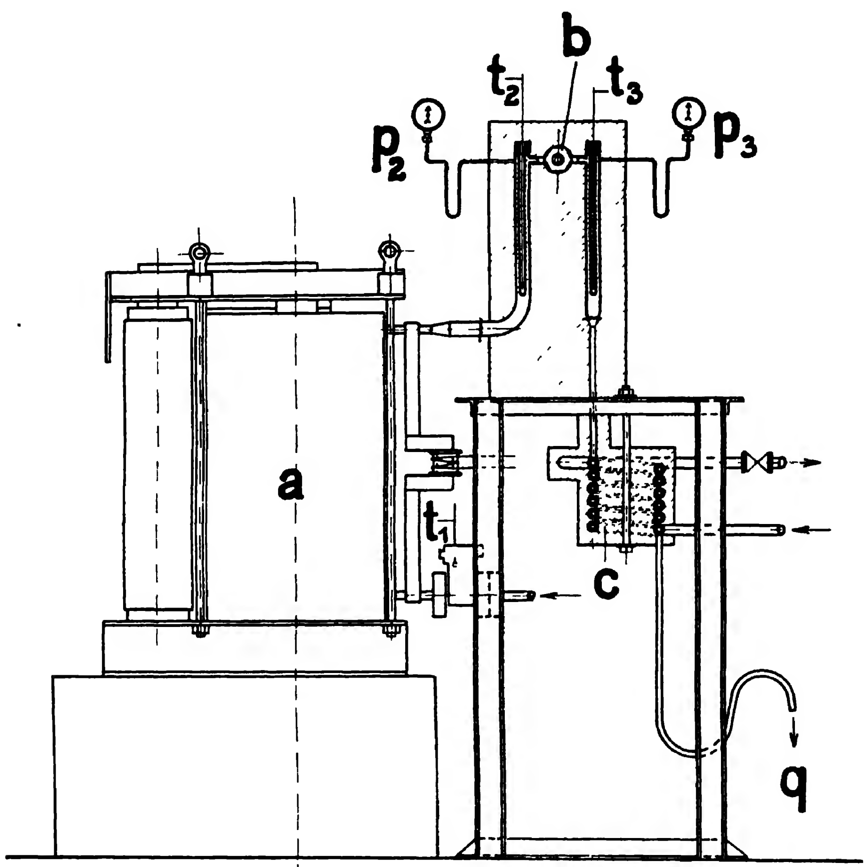


Fig. 4.

a Transformer, boiler.
b Throttling valve.
c Condenser.

station should be set up in the electric power station of the Vítkovice Coal Mines at Mor. Ostrava. Engineers of the Prague Technical University took part in the tests. The station was set in action in summer, 1926, and after necessary alterations and completions forty-seven tests were made in August and September, 1926. In December 1926, and January 1927, thirty-six further tests were made, and after further alterations and simplifications of the station

forty-nine other tests in spring, 1927. At present the tests are being continued.

With the aid of the test station, the heat content at a given condition, which is decided by pressure and temperature, is to be

Fig. 5.

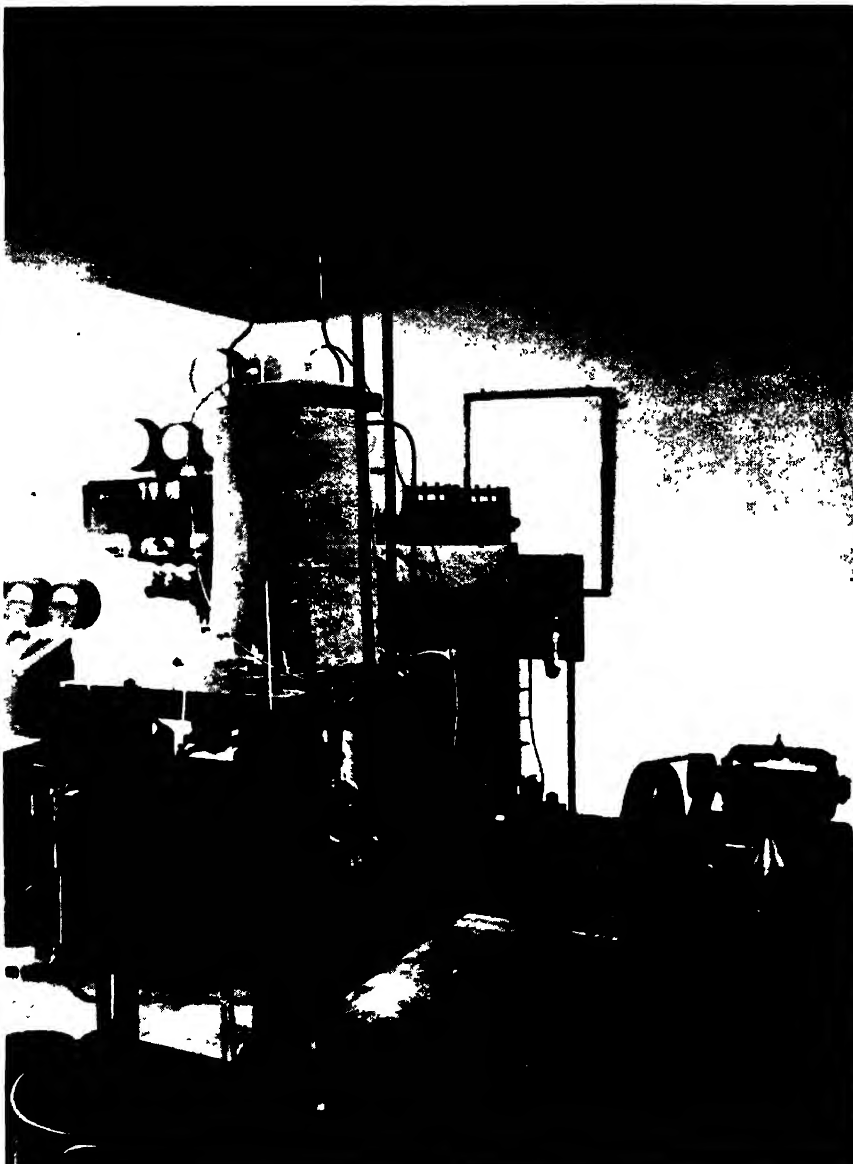


Fig. 6.

measured. The feed pump regularly supplies a certain quantity of water at a temperature t_1 and forces it into the heating coils of the boiler. There the water is warmed, evaporated and, if required, superheated also. Behind the boiler in the measuring-case the temperature t_2 and the pressure p_2 are measured, whereupon the

steam is throttled by the throttle valve down to a pressure of about 1·2 to 2 atm. abs., and in a case placed directly behind the valve the temperature t_3 and pressure p_3 are measured. The steam is finally condensed in the condenser and its heat content Q_2 is ascertained by measuring the cooling water quantity and its temperature increase. On leaving the condenser, the temperature of the condensate t_4 and its quantity q are measured. The measuring equipment is very simple; there are no flanges, all pipe connections are welded, the gland of the throttle valve is under very slight pressure and is therefore completely tight. The quantity of heat supplied, Q_1, is measured by the wattmeter set in the secondary circuit of the transformer. The losses are only the heat losses of the plant. It therefore follows that:

$$Q_1 = q(H_{t_2p_2} - H_{t_1p_2}) \quad + \text{ heat losses}_1 \ldots\ldots\ldots (1)$$
$$qH_{t_2p_2} = qH_{t_3p_3} \quad + \text{ heat losses}_2 \ldots\ldots\ldots (2)$$
$$q(H_{t_3p_3} - H_{t_4p_0}) = Q_2 \quad + \text{ heat losses}_3 \ldots\ldots\ldots (3)$$

Q_1, $H_{t_1p_2}$, $H_{t_3p_3}$, $H_{t_4p_0}$, q and Q_2 are known. H means heat-content. The losses 1, 2 and 3 and the required heat-content of the steam $H_{t_2p_2}$ are unknown. The losses can be ascertained or eliminated by measurements with various values of q, p_2 and t_2 remaining constant. The loss 2 can also be ascertained by selecting the pressure p_2, with constant temperature t_2, within the known limits, somewhere below 20 atm. This loss obviously depends only upon the temperature and not on the pressure. Differences, however, may occur through the various temperatures t_3, resulting from constant t_2 but varying pressures p_2, so that it is preferable to ascertain loss$_2$ and loss$_3$ by altering the measured quantity q.

In designing the equipment, the voltage coil for measuring the electrical energy in the short-circuited secondary circuit was unfortunately not laid close to the windings of the heating coils, but at the place marked A as in Fig. 7. By influence of the magnetic dissipation field resulting from the current flowing in the heating coil and which closes in the space between the pipe and the measuring coil, the measured voltage becomes smaller than the actual, so that the quantity of heat ascertained by the wattmeter is smaller than the quantity actually supplied. The voltage difference can be ascertained by calculation, but this correction introduces a certain element of insecurity into the measurement, so that it was decided not to consider the quantity of heat Q_1 in the calculation but to work only with the equations (2) and (3). The temperature measurement was made with iron-constantan thermo-elements and

precision millivoltmeters from Hartmann & Braun and with mercury thermometers from Messrs. Richter & Wiese, Berlin. These thermometers were first calibrated in the factory and after a test period of about half a year in the State Physical Institute in Berlin. The latter calibration was carried out at higher temperatures, the correction being rounded off to ½°C. The temperature losses by the

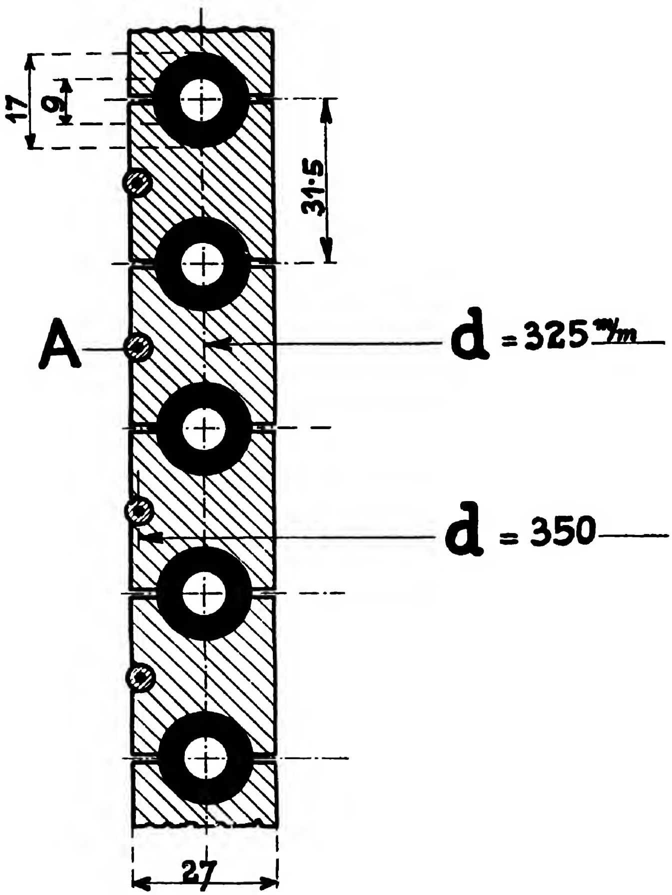


Fig. 7.

radiation of heat from the measuring tube to the insulated tube walls of the measuring case were ascertained by a method of calibration as follows: a second measuring case like the case used for the tests but with a wider external tube was installed and connected first in parallel, afterwards in series. Between the tube and the ribbed case for the thermometer, a thin pipe was let in, surrounded from both sides by steam, in order to eliminate (in a well-known manner)

radiation losses. The quantity of steam flowing through was led into the condenser, where it was condensed and measured. The

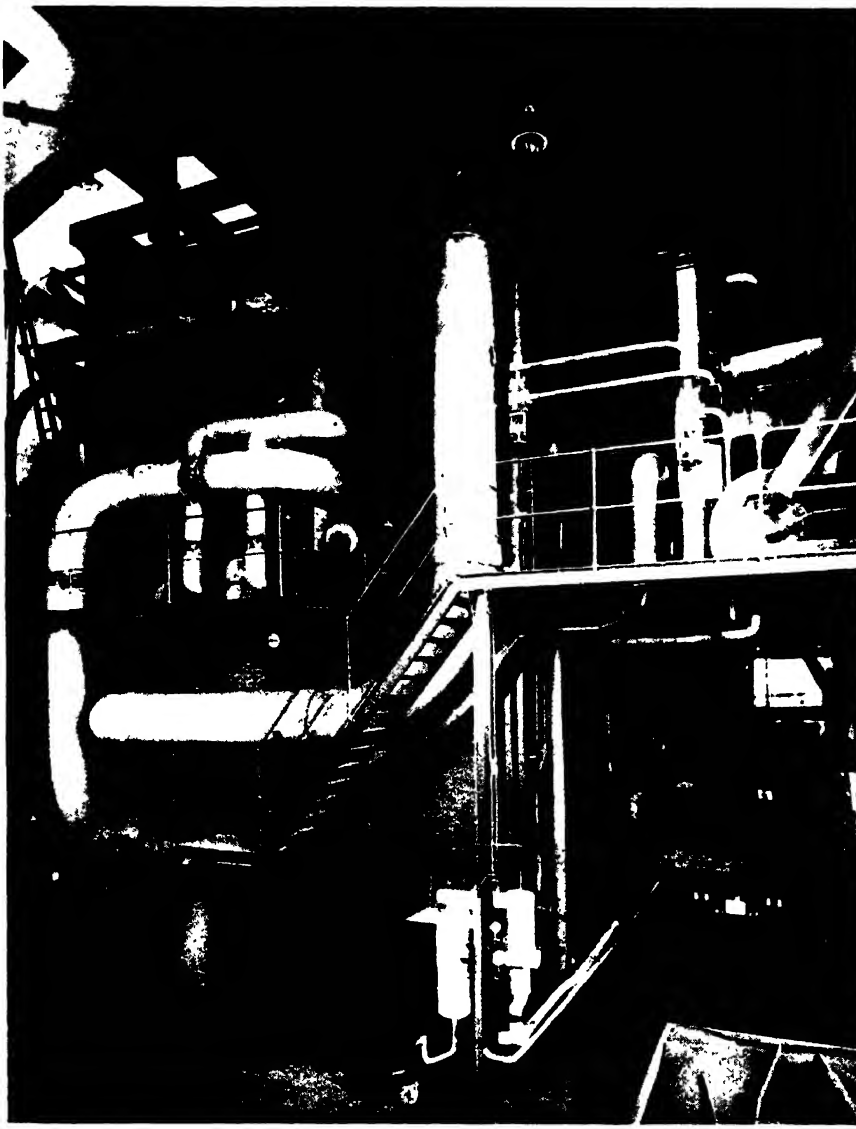


Fig. 8.

tests were carried out at 12 atm. and at 100 atm. (the steam is taken from an 18 tons steam per hour Löffler boiler) with varying quantities of steam and at various temperatures. Between 300°C. and 500°C.

and according to the speed of flow, a correction resulted of +0·6°C. to +0·9°C. In all measurements, corrections were made for the

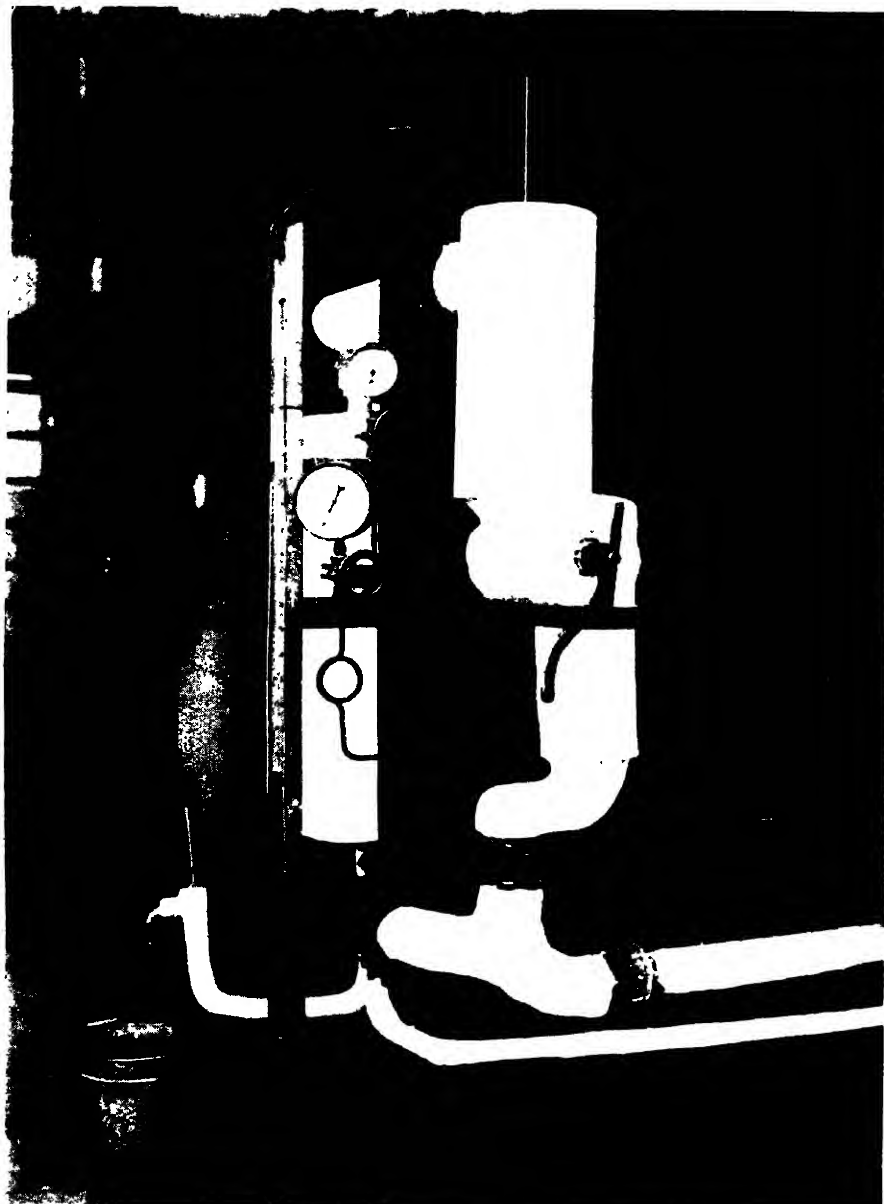


Fig. 9.

mercury thermometers on account of the projecting thread. Preference was given to measurements with mercury thermometers,

because the calibration curves of the thermo-elements as supplied by the manufacturers showed a difference of some degrees in comparison with the curves we obtained ourselves in our laboratory at higher temperatures.

The pressures are measured by pressure gauges from Messrs.

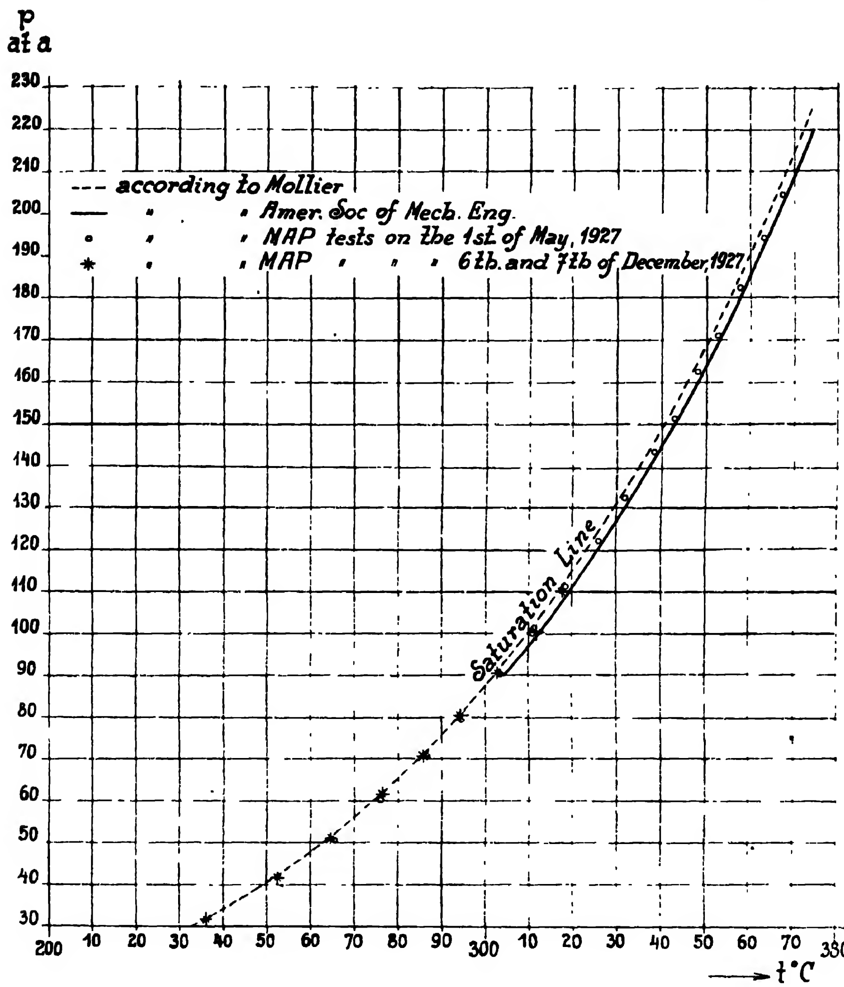


Fig. 10.

Rosenkranz, Dreyer & Droop, Hanover. The pressure gauges are calibrated by the State Physical Institute in Berlin and are also calibrated from time to time anew in our testing plant by a calibrating equipment working with compressed oil and loading weights, and supplied by Messrs. Rosenkranz, Dreyer & Droop.

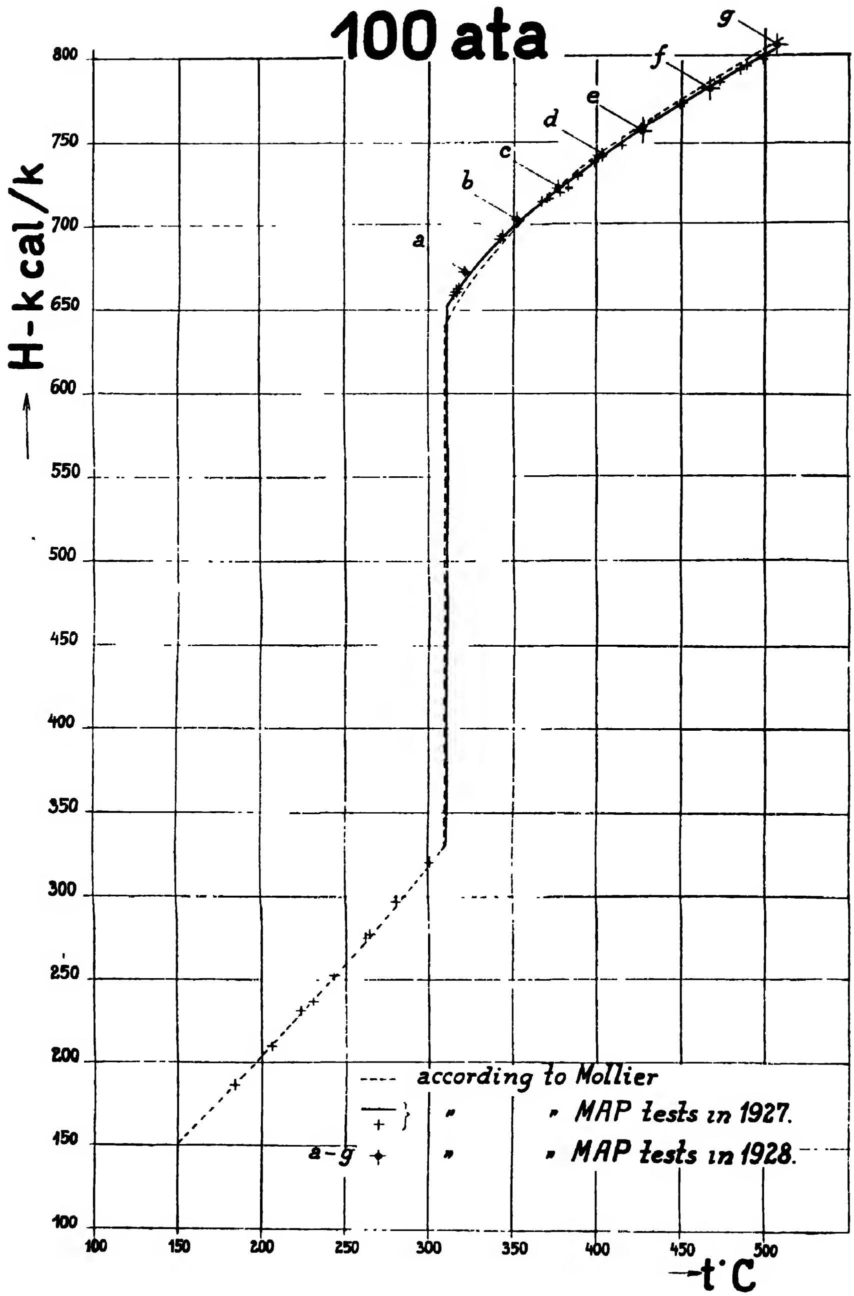


Fig. 11.

To ascertain the accuracy of the measuring equipment as given in Figs. 4, 5 and 6, comparative measurements were made with a similar throttling chamber, but designed for larger quantities of

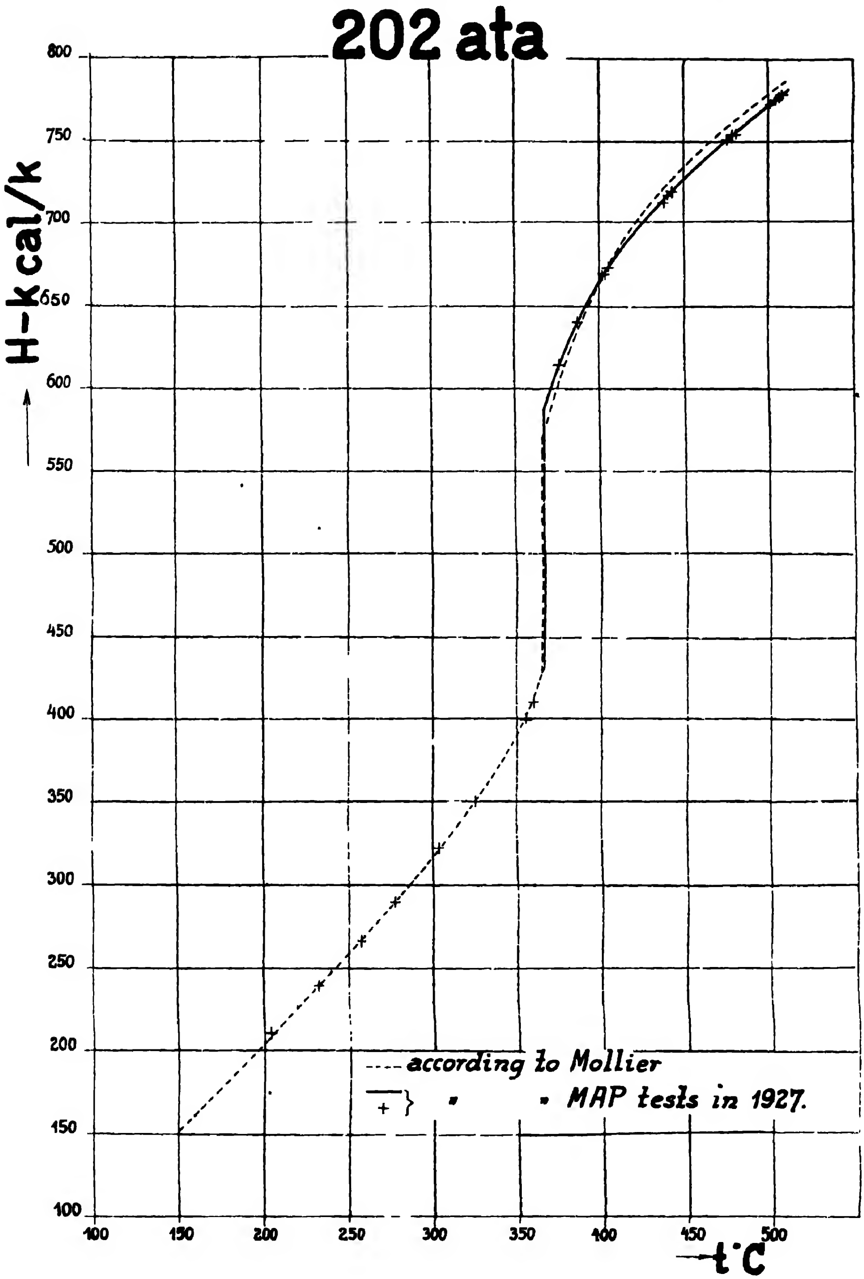


Fig. 12.

steam, with a condenser connected behind. The ribbed measuring jackets of the thermometers are protected against radiation losses by thin tubes, jacketted on both sides with steam. The steam to

be measured is taken from the Löffler high-pressure boiler, mentioned above. The measurements are always carried out twice, once for 60 Kg. steam per hour and once for 120 Kg. per hour. These tests, in consideration of the maximum pressure of 120 atm. in the Löffler boiler, can only be carried out up to this pressure. This test equipment can be seen in Figs. 8 and 9. Behind the equipment, the 18-ton/hour Löffler boiler for 120 atm. and 500°C. can be partly seen.

With the measuring equipment of the M.A.P. (Figs. 4, 5 and 6) as well as with the equipment connected to the Löffler boiler (Figs. 8 and 9) informative measurements of the boiling temperatures at different pressures were made. Thus our results can be compared with the measurements of the American Society of Mechanical Engineers, and the exactitude of our measurements of pressures and temperatures can be controlled. The results we obtained are shown on the enclosed Table 10. Final measurements of the boiling temperatures are proposed to be made by us later on with the tank of the boiler, when the latent heat of evaporation willl be measured.

To refer now to our chief measurements, and the results obtained up to now (March, 1928).

As described above, the heat contents of the water or of the steam are measured by

1. The heat supplied,
2. By throttling,
3. By condensation of the steam.

The three values thus obtained are equalised after the necessary corrections.

Up to the present these tests have been made for 100 atm. abs. 202 atm. abs. and 253 atm. abs. with a simple water quantity $q.$, (Figs. 11, 12 and 13). The control measurements carried out for 100 atm. abs. with simple and double quantity of water are shown in Fig. 11. Similar checking tests are to be made with the larger equipment connected to the Löffler boiler.

The control tests are to be considered as of greater accuracy. Corrections similar to those of the curves for 100 atm. abs. will be made to the curves for 202 and 253 atm. abs. The test-curves are to be established for 50 atm. abs., 100 atm. abs., 150 atm. abs., 200 atm. abs., 250 atm. abs. and for 300 atm. abs. (eventually also for intermediate pressures) up to 500°C. After this, the equipment will be altered and the heat-contents of the saturated steam of 50 atm. abs. up to the critical pressure as well as the boiling temperatures at these pressures will be measured. From the progress of

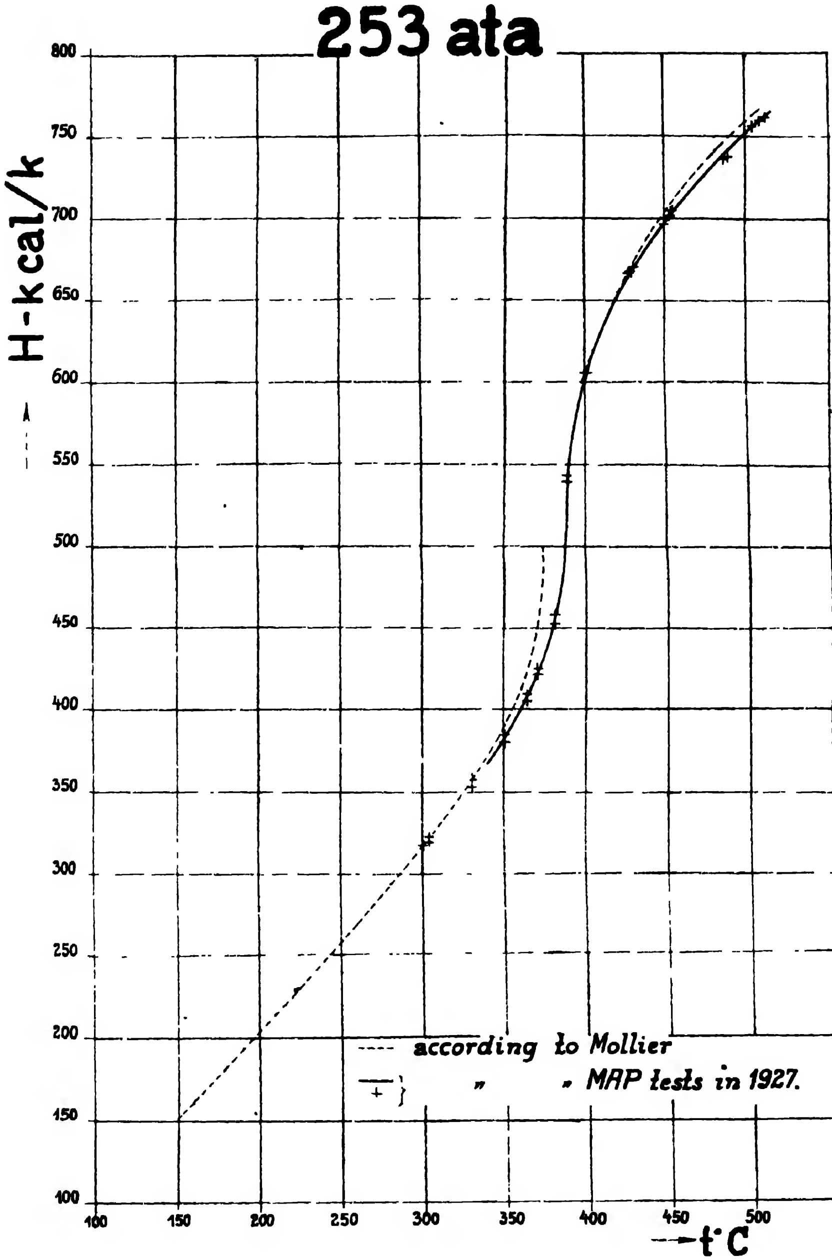


Fig. 13.

the curve of the heat-contents the specific heats and the entropy will be calculated, and (by employing the equations of thermo-dynamics) also the specific volumes. The process is different from the process

adopted by the American Society of Mechanical Engineers (Progress in steam research).

We hope to obtain by these proceedings values of the physical qualities of high-pressure steam sufficiently exact to serve the requirements of the engineer.

ZUSAMMENFASSUNG

Ueber den Vorschlag des Verfassers hat die Masaryk Akademie der Arbeit in Prag anfangs 1924 beschlossen, eine Versuchsanlage zu errichten, mit welcher die Wärmeinhalte des Hochdruckdampfes bis über den kritischen Druck und bis 500°C gemessen werden sollen. Auf Grund dieser Messungen sollte dann ein Entropiediagramm entworfen werden.

Die Mittel hiezu gab die Masaryk Akademie der Arbeit, das Ministerium für öffentliche Arbeiten und einen grössten Teil die tschechoslovakische Industrie.

Die Anlage wurde in der elektrischen Zentrale der Witkowitzer Steinkohlengruben in M.-Ostrau im Jahre 1926 aufgestellt.

Mit der Versuchseinrichtung soll der Warmeinhalt bei einem gewahlten Zustand, der durch Druck und die Temperatur bestimmt ist, gemessen werden. Die Speisepumpe liefert gleichmassig ein bestimmtes Wasserquantum q bei einer Temperatur t_1 und drückt es in die Heizschlangen des Kessels, in welchem das Wasser angewarmt, verdampft und wenn gewunscht auch uberhitzt wird. Hinter dem Kessel in der Messkammer wird die Temperatur t_2 und der Druck p_2 gemessen, daraufhin wird durch das Drosselventil der Dampf abgedrosselt auf einen Druck von etwa 1,2-2 at abs und in einer gleich dahinter geschalteten Messkammer wieder die Temperatur t_3 und der Druck p_3 gemessen. Der Dampf wird schliesslich im Kondensator niedergeschlagen und seine Warmemenge Q_2 durch Messung der Kuhlwassermenge und deren Temperaturzunahme bestimmt. Beim Ausfluss aus dem Kondensator wird die Temperatur des Kondensates t_4 und die Kondensatmenge q gemessen.

Aus bisherigen (Marz 1928) 150 Versuchen wurden die Siedetemperaturen von 50 at bis 220 at ermittelt (Tafel 10.) Es sind vorläufige, noch nicht kontrollierte Messungen. Ferner die Wärmeinhalte bis 500°C fur 100 ata (Fig. 11), für 202 ata (Fig. 12) und 253 ata (Fig. 13). Davon wurde erst die 100 ata Dampfüberhitzungslinie kontrolliert und richtiggestellt. Die Kontrolle erfolgt durch zwei Parallelversuche bei einfacher und doppelter Messdampfmenge, wodurch die Eigenverluste der Messeinrichtung eliminiert werden.

Umgekehrt vom Vorgang bei den amerikanischen Versuchen der Society of Mechanical Engineers messen wir die Wärmeinhalte und wollen die spez. Volumina errechnen.

Wir hoffen, nach dieser Art fur den Bedarf des Ingenieurs genugend genaue Werte über die physikalischen Eigenschaften des Hochdruckdampfes zu erhalten.

THE COMBUSTION OF TERTIARY COAL ON SHIPS OF THE ROYAL DUTCH PACKET NAVIGATION CO. IN THE INDIAN ARCHIPELAGO

DUTCH EAST INDIAN NATIONAL COMMITTEE
WORLD POWER CONFERENCE

H. TH. BAKKER

Paper No. J4

CONTENTS

"It must be understood, once and for all, that efficient and economical firing is a highly skilled occupation, much more so than many other jobs generally accepted as skilled work and paid for accordingly." CHARLES F. WADE, A.M.I.MECH.E., A.M.I.E.E., "A Manual of Fuel Economy." London, 1924.

I—INTRODUCTION

The K.P.M. (Royal Packet Navigation Co.), the largest steamship company for inter-insular traffic in the Dutch East Indian Archipelago, possesses 136 ships, with a gross tonnage of 266,000 tons. Ten of these are motor-ships, with a total gross tonnage of 21,750; the other 126 are steamships. In twelve ships the steam is generated by liquid fuel (42,550 tons gross), while the other 114 (201,700 tons gross) are fired by coal.

The class of coal available is all of the Tertiary age. Of this coal the company uses more than 400,000 tons (1,000 Kg.) a year. Originally many difficulties were encountered in burning this coal efficiently on the commonly used grates, but, as a result of experience gained, many an engineer now prefers the native coal to the solid fuel ecountered in European practice.

About 60 per cent. of the coal required is supplied by the collieries owned by the K.P.M., situated in East Borneo. The balance is supplied by mines owned by the Government and some private companies.

In most cases the average "run of mine" coal cannot be used on board the ships, as a considerable quantity of fine slack-coal would be lost through "riddling." Therefore, in most collieries the coal is screened. The company's own mine supplies :—

Lumps above 3 cm.
Nuts from 3 to 1 cm.
Slack-coal below 1 cm.

The coal bought by the company from other mines is almost exclusively lump, although the company takes a growing interest in the slack-coal from other mining companies, as this cheap fuel may be burnt with good results on mechanical stokers, with which most of the newly-built ships of the company are equipped.

II—PROPERTIES OF DUTCH EAST INDIAN COAL AS TO COMBUSTION

The proximate analyses of the different kinds of native coal used by the company do not vary widely, as far as the moisture-free matter is concerned. This coal always contains a high percentage of volatile matter, the proportion to fixed carbon being

about 7 : 10. The amount of ash differs to a greater degree, also the percentage of moisture. Both ash and moisture have the greatest influence on the commercial value of the coal. Some average proximate analyses of the kinds of coal as fired may be found below (air-dry coal):—

Name	Total moisture per cent.	Volatile matter per cent.	Ash per cent.	Fixed carbon per cent.	Calorific value (calories)
Beraoe (company's own mine) ...	10	35	3	52	6,500
Ombilin (Government exploitation)	9	34	2	55	7,000
Martapoera	7	35	3	55	7,000
Samarinda	10	38	2	50	6,500

The amount of *total moisture* is usually high. Part of this, however, is free moisture. This makes the coal liable to rapid weathering; it will easily become triturated and be subject to spontaneous heating. In some places the coal is stacked in covered coal-sheds, as, for example, at the company's own mine, where 10,000 tons can be stacked under cover along the bank of the river, and where the ships come alongside for bunkering or loading. But on most coaling-depots, spread all over the Dutch East Indian Archipelago, coal is stacked in the open air. Especially in the wet monsoon, the total amount of moisture, therefore, will be considerably larger.

The amount of volatile matter is also very high. This has been the greatest difficulty to be overcome. In the beginning our engineers, who were accustomed to European firing methods, could not determine the best method of burning this light coal, as shortly after having been placed on the fire, the gases escape violently from the fresh coal. As these gaseous products do not find sufficient air for total combustion, a heavy black smoke escapes from the funnel, and a large percentage of fuel is thereby wasted. As soon as the distillation of the volatile hydrocarbons is completed, the layer of coked fuel has become too thin, and holes are easily blown in the bed of incandescent coal. It will be clear that when a fresh charge of coal has been placed on the firegrate there will be a shortage of air for proper combustion, while, on the other hand, when the volatile matter is all distilled off, there will be a danger of excess air being admitted. The generation of heat, therefore, will vary, and especially on board ships, it will be very difficult to keep the necessary constant steam-pressure in the boilers. Later in this paper the right method of firing will be discussed.

Comparisons have been made between the native coal and the bituminous European and American kinds of coal. There is some similarity indeed, but to apply the results of experiments carried out on carboniferous coal, containing a high percentage of volatile matter, to native coal would not be correct. The geologically much older coal may have the same proximate analysis as our native coal, but it will not ignite so easily, nor give up its contents of volatile matter so quickly after having been placed on the fire. It, therefore, will be necessary to burn the carboniferous *bituminous* coal, which is apparently so similar to the native coal, in a relative thin firebed with a large surface, whereas the native coal must have a thicker firebed with a smaller surface.

The percentage of ash is low. This, however, is not characteristic of native coal in general. On the contrary, the Tertiary coal in which the East Indian Archipelago is very rich, usually possesses too high a proportion of incombustible matter for it to be used in the raw state. But, luckily, also, a large quantity of coal is available with a low percentage of ash, and this class of coal is principally worked. The composition of the ash in the fuel used does not vary very much. Although the ash mostly contains some iron (owing, partially, to a never-failing percentage of iron-pyrites in the coal), the fusing point is almost never so low as to cause the forming of solid slags. The Beraoe coal, in particular, has a light, almost white ash, that does not form masses of clinker. Other classes of coal may give ash that will be liable to produce a solid slag, but, as a rule, the total amount of ash is not large enough to form masses of clinker, which would give trouble with the air supply.

Owing to the high proportion of volatile matter, the percentage of fixed carbon is evidently low. In the fire the coke is brittle and will not form a solid mass.

The calorific value will be found sufficient for a good steam coal, but, as already stated, owing to the amount of moisture the heat generated will be considerably lower than this calorific value. Nevertheless, the K.P.M. nowadays almost exclusively uses native coal on board its ships; and the burning of this coal has been brought to a complete success, so that, should less bituminous coal from other countries be available at the same price, the company probably would confine itself to native coal.

III—Hand-Firing of Native Coal

On board most of the ships of the K.P.M. the boilers are fired by hand. (Natural draught: thirty-three ships—29,250 tons gross; forced draught: fifty-two ships—128,450 tons gross.) On twenty-nine ships underfeed-stokers are employed (44,000 tons gross), to which a separate section will be devoted.

In the preceding section we discussed the characteristics of our coal when burning. In view of the fact that some of it is fired by hand, some further qualities must be mentioned. On board the company's ships, the firemen are almost exclusively natives. The Javanese firemen, provided they are under good supervision, will be sufficiently skilled to do their work at the hot fire-places in the tropics, but physically they are not very strong; they have little endurance and, consequently, are not fit for constant heavy work. We stated before that the class of coal used is lightly triturated. Even lumps are, through successive handling, already reduced to the size of larger nuts when they arrive at the fire-places. Further, since a good firing method requires this coal to be placed on the fire in small quantities only, it will be seen that this class of coal specially suits the capabilities of the men employed. The Javanese firemen, if not constantly controlled, are rather easy-going. When no engineer is in sight they will place as much coal on the grate as possible, in order not to let the steam pressure in the boiler come down, after which they can rest for a long time, only at long intervals regulating the air supply as combustion goes on. On some ships the possibility of this uneconomical way of firing is prevented by cutting off half of the coal scoop. It must, however, be remarked that, when doing this, the fire-doors must stay open longer to place a certain quantity of coal on the fire. We therefore do not recommend this as a remedy. The Javanese fireman will not take more coal on his shovel than he can easily handle, so we think that this matter regulates itself to the proper extent, but at all times good supervision is necessary.

From the preceding it will be obvious that *native coal for complete combustion will require:—*

1. *A not too thin firebed evenly spread,* so that the air may be evenly distributed throughout the burning fuel;
2. *A feeding of the fire at short intervals* in order to prevent the forming of bare portions in the firebed;

3. *A shortened grate-surface and a large combustion space* in connection with the large amount of volatile hydrocarbons;
4. *Correct air regulation*;
5. *A large quantity of secondary air,* which must be thoroughly mixed with the combustible gases.

Points 1 and 2 do not require further explanation.

Point 3 is very important. As already stated, the ships of the K.P.M., nearly all built on Dutch wharfs, have a complete European boiler equipment. As to the Scotch boilers, it has not proved necessary to change the usual mode of construction. But a firebed of coal with a high amount of volatile matter will in consequence burn away rapidly, and soon will get blow-holes and bare spaces. Moreover, the not very muscular Javanese fireman will not be able properly to cover his firegrates in a long fire, so that the back ends will be more or less bare. This has led to the practice of shortening the fire by putting in one or more rows of firebricks. The shortening varies from one-tenth to one-half of the grate length. Often the grate area is enlarged or shortened even during the voyage.

In the inter-insular coastal trade the distances between ports of call as a rule are very short, and it therefore happens frequently that in order to avoid entering a harbour by night-time the speed will be reduced considerably, and consequently the demand for steam from the boilers is considerably decreased. It also may occur, for nautical reasons, that for part of a voyage "full power" is required, and for part reduced power must be used. To burn a proper amount of coal per square metre of grate area *it will not be possible, under these conditions, to keep a constant grate surface,* especially on steamers with only one boiler. When time is available, diminution of the grate area is effected, as already stated, by placing one or more rows of firebricks on the firebars *before* the boiler is heated. When time is not available, and the consumption of steam is considerably lowered, the back part of the firebars is kept covered with ashes and clinker. Should it be necessary on a longer run to use a shortened fire first and a longer one afterwards, often one row of firebricks is laid loose on the bars, only fastened by steel keys. These bricks can be easily removed with the slice and the rake, while the firing is going on.

It is a well-known fact that *a high rate of combustion per square foot of grate area will result in high furnace temperatures.* This

will give a high generation of radiant energy. It is, therefore, necessary to shorten the firegrate area as much as possible. The rate of combustion on board the ships of the K.P.M. has a maximum rating at 100 Kg. of coal per hour per square metre of firegrate surface for natural draught, and 160 Kg. per square metre for forced draught. The rate of combustion must not be made too high, as the air regulation will then be difficult and big losses in the flue-gases cannot be avoided.

It is usually impossible *to alter the combustion space,* but in some cases *the level of the firegrates has been lowered* with this object. One may say that diminution of the grate surface relatively enlarges the combustion space, but as, in that case, the rate of combustion per square metre is raised, the combustion space is again relatively reduced. Supposing that the combustion space of an ordinary boiler is constructed for a class of coal with 15 per cent. of volatile matter, while, when firing native coal, the rate of combustion per square metre of grate area v. European coal is raised from 120 Kg. to 150 Kg., and the percentage of volatile hydrocarbons is 35 per cent., then the firegrate surface must be reduced to $\frac{150}{250} \times \frac{15}{35} =$ 54 per cent., in order to keep relatively the same combustion space for the gases to be burnt. Generally, the shortening does not go so far, but it often comes to 40 per cent.

On the strength of these considerations the company has been able to economise considerably.

Fires in the top of the funnel, due to unconsumed gases mixing with fresh air, never occur.

Point 4, the *correct air regulation,* can also only be learned, in the long run, by experience. The excess of air with which this coal is properly burnt is generally about 50 per cent. As the maximum percentage of CO_2 will never rise above 18 per cent., the percentage of CO_2 in the funnel gases will generally be found to be about 12 per cent., with traces of CO and H_2. For the control of the flue gases, the Orsat apparatus is used. Most of the other automatic apparatus, successfully used on land plants, have, on account of their construction, failed on board a rolling and pitching ship. It is indeed a fact, that in very bad weather the Orsat apparatus also cannot be used, as the reading of the levels of the liquids is impossible, but under not too adverse conditions the Orsat apparatus has proved to be successful.

The regulation of the air supply in boilers with forced draught is firstly done by varying the revolutions of the fan. On board the small ships a good deal of the available pressure-head is lost owing to resistance in the narrow air channels, which cannot be enlarged on account of want of space. Often a pressure of 7 cm. water-gauge in front of the boiler is lowered through loss to 2 cm. In the Scotch boilers equipped with Howden fronts this air is preheated and afterwards divided into primary and secondary air. Naturally there is a damper in the air inlet from the main air channel to the boiler, which, when the boiler is under service, will be wide open. Behind this damper only the supply of secondary air can be regulated separately. Generally, there is a tendency to use too much air, in order to produce a very light smoke. We, therefore, often find, when making an Orsat analysis, a percentage of CO_2 that is too low. In such a case, the revolutions of the fan are first of all reduced, in order to lower the total amount of air. This is continued until, by Orsat tests, some unburnt gases are found. Suppose the percentage of CO_2 is found to be 10 per cent. Now, by keeping the total supply of air constant, the ratio of secondary air is increased at the cost of the primary air, till the unburnt gases have disappeared; the percentage of CO_2 then will slightly rise. Probably it will be possible further to reduce the revolutions of the fan, and perhaps, again, the ratio of secondary air can be increased, this being continued till the highest possible percentage of CO_2 is reached, in accordance with the lowest possible percentage of unconsumed gases. In most of these cases the funnel gases will be rather more black than was the case before the air was regulated to the proper extent. This will be evident, for the same amount of soot and fine ash is now spread through a less volume of funnel gases.

It may be pointed out here that on board ship, through lack of space, the air channels often cannot be installed in such way as to allow an easy flow of gases. Too many curves must be made with too small a radius, or even at right angles, especially when secondary channels must be branched off. The division of a flow of air into two parts should, when possible, always be made by a Y-branch, with a damper in each branch channel, in order to be able to regulate the quantity of air passing in each channel.

In the case of hand-fired boilers, the fire is charged intermittently and therefore the amount of necessary air is not always the same. In Scotch boilers with Howden's forced draught, the inlet of

secondary air is closed automatically when the firedoors are opened. With water-tube boilers, hand-fired, this method is not used. It will be evident that, when opening the firedoors, the amount of secondary air is considerably increased. It is, therefore, a good practice *to maintain only a little draught over the fire*. On the other hand, when a fresh charge of coal is fired, the evolution of the hydrocarbon gases is so great that an extra supply of air is highly desirable. However, this air, entering through the firedoors, is not preheated, and especially in Scotch boilers could cause damage to the boilers. This is one of the reasons why, more and more, on the ships of the K.P.M., *the fire-bridges are bricked up*, only leaving *a semi-annular opening*. The inflowing cold air will first cool the burning and already burnt gases, but the mixture is intensively heated when passing the hot, high fire-bridge before entering the combustion chamber.

The practice of bricking up the fire-bridges has further advantages, which should be mentioned here :—

1. There will not be too much draught (owing to the natural draught of the funnel) in the combustion space, due to the resistance of the narrow (nearly 5 in. wide) semi-annular opening.
2. *The heat is concentrated in the flues,* a higher temperature is reached in the fire, and consequently the ratio of radiation is increased.
3. *The burning gases are thoroughly churned and mixed* with the secondary air, so that complete combustion is ensured. The combustion is to a large extent completed before the gases reach the combustion chamber.
4. The narrow semi-annular opening provides for *a better transfer of heat,* owing to conduction and convection.

As a good fireman, charging his fire at short intervals, will keep the thickness of the firebed nearly constant, the amount of air for combustion is also nearly constant. Once determined with the tests of an Orsat apparatus, the revolutions of the fan and the positions of the dampers in the air channels can stay fixed for each demand of steam. The colour of the smoke and the temperature of the funnel gases, then, are the indicators for an economically fired boiler (smoke slightly black; temperature of funnel gases without superheater 300°C.; with superheater 250°C.).

In boilers with natural draught the regulation of the air supply is more difficult. It is the experience of the K.P.M. that *native coal can be best fired with forced draught,* as only in that way the air necessary for combustion can be sufficiently regulated. With a varying funnel-draught, especially on board a ship with the wind from behind, also variation in the position of the dampers will be necessary, and this is too difficult for the native firemen to understand.

In the mechanically fired boilers, which at present are always B. and W. watertube boilers, the fire is charged regularly, and, with a special sort of coal, it is possible to fix the air supply for every condition of steam generation. The Orsat apparatus can then be used only as a control once per watch of four hours per boiler, but the temperatures of the funnel gases must be read at shorter intervals. In this case, the secondary air (generally not preheated) is usually supplied in the front *and* at the rear of the watertube boiler, in order to be sure that the gases shall have enough air for complete combustion. This is especially necessary on board the smaller vessels with one main boiler, which is fired "from the rearside." On these ships the stoker front is placed in the rear wall of the boiler, so that the steam drum with the gauge glass can be seen from the engine room, and can be easily observed by the engineer on watch. The position of the baffle plates, however, remains unaltered, and it will be understood that the burning gases now cannot rise directly to the watertubes, but must first return to the ordinary boiler front. In order to supply sufficient air to the combustible gases, a jet of secondary air is necessary in front and at the rear end of the boiler.

IV—Mechanical Stoking

In order to secure greater economy in coal burning, and also to be able to burn the cheaper slack coals, the K.P.M. has tried the application of mechanical stokers on watertube boilers. Although in Scotch boilers mechanical stokers have also been tried, and experiments are still carried out in order to solve this problem, these experiments have not yet been successful. Under present circumstances nearly all new steamships built for the company are equipped with watertube boilers fired by mechanical stokers. Only some of the largest passenger ships burn liquid fuel, mostly with a view to the cleanliness of liquid fuel bunkering and burning. Investigations recently made with over twenty ships

of the K.P.M., which some fifteen years ago were fired by liquid fuel (petroleum residue), and have now for a long time been coal-fired, showed that against 100 Kg. of coal 55 Kg. of liquid fuel must be burnt. The average heating values are:—10,000 calories per Kg. for liquid fuel, and 6,600 calories per Kg. for coal. The boiler efficiency is raised from 58.5 per cent. (coal) to 70 per cent. (liquid fuel) in Scotch boilers. Notwithstanding this and other advantages of liquid fuel, the price makes it prohibitive for general use.

At present, forty-seven watertube boilers on twenty-nine ships, with a total gross tonnage of 44,000 tons, are fired by underfeed-stokers. The underfeed stoker has been chosen as this is the only mechanical stoker suitable for watertube boilers, which, even if the mechanical part gets out of order, can be fired by hand, through ordinary firedoors. (This subject is more completely dealt with in a lecture read at the summer meeting of the sixty-fourth session of the Institution of Naval Architects, held in Holland, September 5, 1923, by W. J. Muller, Esq., M.E. (Delft), Associate Member, on the subject: "A Few Results from Practical Experience with Mechanical Stokers, applied to Marine Watertube Boilers.")

It will be evident that *the underfeed principle is especially suitable for coal with a high content of volatile matter,* as the fuel is coked before combustion, and ignition of the combustible gases is certain when passing through the incandescent layer of burning coal, provided the supply of fresh air is correctly regulated.

The arrangement of the underfeed class E stoker for large boilers of the externally fired type is too well known to need discussion in detail. A short summary of the operation, together with the principal features we have to deal with when firing native coal, follows:—From a hopper in front of the boiler, the coal, of which the bigger pieces must have been broken before, is conveyed under the fire by means of a reciprocating sliding bottom, which runs the full length of the trough. As the coal rises from the trough, it is distributed to the sides of the furnace by moving bars. Finally, the remaining clinker and ash are deposited on the dumping trays along each side-wall. This is performed by the action of the moving side-bars, which are made to rock to and fro. The stoker is self-feeding and self-cleaning. The rate of feed can be regulated within considerable limits, which, of course, is necessary on board steamships.

As already stated, the lump coal must be broken beforehand into pieces of about 1 to 3 cm. When this is not done the sliding bottom will have to do too much work, and is almost used as a crusher, for which it is not built. Most of the lumps have, through various stages of handling, become triturated before being dumped in the hopper, and difficulties are only encountered when fresh lumps are bunkered at the collieries. It will be evident that nuts and slack-coal, owing to their smaller size, are very suitable for the underfeed stoker.

The principles of air regulation, when burning lumps or nuts in the underfeed stoker, are the same as already mentioned in the chapter about hand-firing. When slack-coal is used, special difficulties have to be considered. The fine coal is compressed in the trough, and consequently the air from the wind-box (which should partly enter the trough through a number of holes in the side-bars and partly should pass through the hollow side-bars) now finds too much resistance in the compact mass of compressed fine coal. The air will, therefore, be inclined to pass exclusively through the side-bars. The air that should enter the trough serves to mix with the gases that are formed by the coking effect. The mixture of air and inflammable gases should ignite in the layer of coal in the trough, at the point where the temperature is high enough. Again, the burning gases in the layer of coal contribute greatly to the coking effect, and the surface of the coal in the trough should, therefore, be seen as an incandescent mass. But when no air, owing to great resistance from the compressed coal, can enter the trough, the combustible gases only just find sufficient air for combustion when they escape from the layer of coal. Naturally, there will in this case be a greater chance of incomplete combustion when secondary air is not present in sufficient quantity, and the mixing of air and gases is not well effected. The heat in the furnace only will usually not be large enough to ignite the layer of coal in the trough, and the surface of the retort will, in this case, be seen as a black space on the grate.

It will be clear that a remedy can be found for these difficulties by *increasing the resistance of the secondary air in the hollow firegrates.* This is done by placing cross-bolts in the air channels of the grates. Thereby the pressure of the air in the wind-boxes under the grates is also lowered, whilst the formerly encountered difficulty of the generation of much fine coke-dust and ashes has also been overcome. When firing slack-coal, without the crossbolts

put in, excessive soot blowing was necessary, because the strong flow of air through the firebed picked up so much coke and dust particles, which afterwards were deposited on the tubes of the boiler, and also in large quantities on the deck of the ship.

In the last two years steam superheaters have been used on the marine watertube boilers of the company's ships. The superheater is placed between the first and second row of baffle-plates and fitted with a sliding lid, so that it may be placed partly or wholly in a bye-pass. Steam temperatures of 300°C. have been easily maintained, the boiler efficiency being raised to 80 per cent.; CO_2—12 per cent., funnel temperatures 250-300°C.

When stoking mechanically, the secondary air is, in most cases, supplied in the front *and* in the rear wall of the boilers.

As to the grate area, this is mainly regulated automatically by the underfeed itself. If not much steam has to be generated, the sliding bottom only makes a few strokes a minute (it may be varied from one stroke in three minutes to fifteen strokes in one minute). When not much coal is fed into the firebed, the coal will be entirely burnt before arriving on the dumping trays, and the remainder of the grates are not active, and remain covered with ashes and clinker. But here a difficulty is encountered, for the ashes of most native coals do not clinker; they have often an almost white colour and are very light. The primary air preheated in the hollow firebars, enters the wind-boxes at the sides near the dumping trays. This air will seek the shortest way to escape, and, therefore, will try to blow away the ashes, but will not pass the firebed on the active part of the grate.

In most cases, when the boiler load is small, an excess of air must be given in order to maintain combustion, the secondary air-ports must be shut. The Orsat analysis shows only 6 per cent. of CO_2, together with unburnt gases, so there must be an excess of air, which is not properly mixed with the combustible gases. When the ashes are somewhat apt to clinker, or when the proportion of ash is larger, this difficulty it not so liable to be encountered.

When the boiler load is at maximum the grate area is, in most cases, large enough. The native coal, as a rule, is readily inflammable and burns away rapidly in consequence of the high content of volatile matter. But when the coal, especially slack-coal, contains a high amount of incombustible material, the grate-area, of course, must be larger than when burning lump coal with

only a low percentage of ash. The grate surface then, sometimes proves to be too small and the maximum load cannot be reached. To improve this, a few alterations have been made, in order to admit air from the air chambers to the ashpits below the dump trays, which now get air spaces, and sometimes are made double. By opening a sliding lid, the preheated air is admitted to the ashpits; and the coal on the dumping trays, that is not quite burned out, can now burn completely. In this way, the grate area can be enlarged, and the dump trays be arranged as secondary grates. But this remedy should only be used in case of emergency, for dump trays cannot at the same time be used to burn coal and to dump ashes. When dumping is necessary (and when burning native coal, which needs a large grate area, *i.e.*, which contains much ash, dumping will be *often* necessary), as a matter of fact, unburnt coal always will be dumped as well. Furthermore, the dump trays are not cooled strongly enough and will be burned themselves. In most cases, this special arrangement, therefore, is not necessary, as the amount of steam required in ordinary practice can be produced when using underfeed stokers without secondary grates with nearly all kinds of coal.

The average height of the watertubes over the grates has been increased by 1 ft. 8 in., thus increasing the cubic capacity of the combustion chamber in order to get complete combustion of the combustible gases with the secondary air before they enter the first row of watertubes. A maximum of heat will in this way be absorbed by the water, which permits the reduction of the temperature of the escaping gases to a minimum.

Conclusion

In the above paper, only a concise and simple account could be given of the results obtained by the company with the firing of native coal. Much more can be said on this subject and experiments are constantly being made to get better boiler efficiencies. The experience gathered in the course of years is given in this paper, and it is only due to the collaboration of the whole technical staff of the company that such satisfactory results have been attained.

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ZUSAMMENFASSUNG

Der Bericht behandelt die Verfeuerung von tertiären Kohlen auf den Schiffen der "Koninklyke Paketvaart Maatschappy." Die Flotte besteht aus 136 Schiffen mit 266 000 Tonnen. Davon verfeuern 12 Dampfer (42 550 Tonnen) flüssige Brennstoffe, 33 Dampfer (29 250 Tonnen) Steinkohle mit natürlichem Zug, 52 Dampfer (128 450 Tonnen) Steinkohle mit Unterwind, und 29 Dampfer (44 000 Tonnen) Steinkohle mit Unterschubfeuerung; 10 Schiffe sind Motorschiffe. *Steinkohle*: Verbrauch jährlich rund 400 000 t von 1 000 kg. Ungefähr 60% wird durch eigene Gruben produziert (Stückkohle grösser wie 3 cm; Nusskohle von 3 bis 1 cm; Gruskohle unter 1 cm).

EIGENSCHAFTEN DER VERFEUERTEN KOHLE

Der Wassergehalt ist hoch, in lufttrockenem Zustand ungefähr 10%, aber auf nicht überdeckten Kohlenplätzen viel höher.

Der Gehalt an flüchtigen Bestandteilen, auf lufttrockene Kohlen bezogen, beträgt meistens 35%. Sofort nach Aufwerfen tritt eine sehr schnelle Vergasung ein, wodurch der Luftbedarf gesteigert wird. Aber wenn die Kohlen entgast sind, ist die Kohlenschicht wahrscheinlich zu locker geworden und es tritt Luftüberschuss auf. Die tertiären Kohlen geben ihre flüchtigen Bestandteile viel schneller ab wie karbonische Kohlen von derselben Zusammensetzung.

Der Aschegehalt ist niedrig (2 bis 4%).

HANDFEUERUNG

Für vollständige Verbrennung von tertiären Kohlen ist nötig dass:

(1) die Kohlenschicht nicht zu dunn und sehr regelmässig über den Rost verteilt sei;
(2) die Kohlen in kurzen Zwischenräumen aufgeworfen werden;
(3) der Rost so klein wie möglich und der Verbrennungsraum so gross wie möglich sei;
(4) die Verbrennungsluft in regelbaren Mengen zugefuhrt werde;
(5) eine grosse Menge Oberluft zur Verfugung stehe.

Die Verkürzung des Rostes betragt $\frac{1}{10}$ bis $\frac{1}{4}$. Die Rostfläche wird wahrend der Reise häufig verkürzt oder verlängert. Die Rostleistung kann mit künstlichem Zuge bis 160 kg/m² gesteigert werden.

Bei gut geleitetem Vorgange kommt man mit dem 1,5-fachen der theoretisch erforderlichen Luftmenge aus. Der CO_2-Gehalt im Orsatapparat betragt meistens 12%. Man muss viel Oberluft zufuhren.

Die Feuerbrücken werden häufig erhoht, damit:

(1) nicht zu viel Zug im Verbrennungsraum entstehe;
(2) die Wärme im Feuerraum konzentriert werde;
(3) eine gute Mischung aller Gase und Luft stattfinde;
(4) an der verengten Stelle ein besserer Warmeubergang stattfinde.

Diese tertiären Kohlen werden am besten mit kunstlichem Zuge verfeuert.

SELBSTTÄTIGE FEUERUNGEN

Nur in Wasserrohrkesseln mit Unterschubfeuerungen und Unterwind. Es lassen sich Nuss- und Gruskohle hierin gut verfeuern. Gruskohlen werden in der Mulde komprimiert, deshalb mussen die Luftöffnungen zu beiden Längsseiten der Mulde gross sein und der Unterwind kräftig. Die Rostfläche vergrössert oder verkleinert sich automatisch; der nicht aktive Teil der Rostfläche bedeckt sich mit Asche und Schlacke. Letztere sammeln sich zu beiden Rostseiten auf den sekundären Rosten und können selbsttätig entfernt werden. Die sekundären Roste können aber auch die Rostfläche vergrössern, wenn nötig für eine hohe Leistung der Kessel.

MITTEILUNGEN ÜBER DIE BRENNSTOFFWIRTSCHAFT DER DEUTSCHEN REICHSBAHN-GESELLSCHAFT

(FUEL ECONOMY AS PRACTISED BY THE GERMAN FEDERAL RAILWAY CO.)

DEUTSCHE REICHSBAHN-GESELLSCHAFT

ERNST HARPRECHT AND COLLABORATORS

Paper No. J5

CONTENTS

EINLEITUNG

Der Jahresverbrauch der Deutschen Reichsbahn-Gesellschaft an festen Brennstoffen—Steinkohlen, Steinkohlen-Briketts, Steinkohlen-Koks, Rohbraunkohlen und Braunkohlen-Briketts—beläuft sich auf rund 14,4 Millionen t. Bei diesem hohen Verbrauch ist es erforderlich, dass der Auswahl der Brennstoffe, der Überwachung ihrer Güte und ihres wirtschaftlichen Verbrauches besondere Sorgfalt zugewendet wird.

Im folgenden sollen die Massnahmen beschrieben werden, welche die Deutsche Reichsbahn-Gesellschaft zur Überwachung der Brennstoffwirtschaft getroffen hat.

Die Gliederung des Stoffes ergibt sich aus den drei Hauptgebieten dieser Überwachung:

der Güteprüfung, Abnahme und Lagerung,
der Verwendung der Brennstoffe und
der Überwachung des Brennstoffverbrauches.

Die grosse örtliche Entfernung, die Vielartigkeit und grosse Zahl der über das gesamte Reichsgebiet verstreuten wärmetechnischen Anlagen und Betriebe der Deutschen Reichsbahn-Gesellschaft erforderte die Bildung von Wärmewirtschaftsbezirken, die je für

ihren Bezirk die Fragen der Brennstoff-, Wärme- und Energiewirtschaft zusammenfassend bearbeiten. Im ganzen sind 10 solcher Wärmewirtschaftsbezirke vorhanden, die so abgegrenzt sind, dass möglichst gleichartige wärmewirtschaftliche Verhältnisse in ihnen vorliegen.

Die Anlage 1 gibt einen Überblick über die zugehörige Organisation der Brennstoff-, Wärme- und Energiewirtschaft der Deutschen Reichsbahn-Gesellschaft.

Güteprüfung, Abnahme, Lagerung und Ausgabe

Anforderungen an die Brennstoffe. Rund 90% des gesamten Brennstoffverbrauches der Deutschen Reichsbahn-Gesellschaft entfällt auf den Verbrauch der Dampflokomotiven, die übrigen 10% werden in den Werkstätten und sonstigen ortsfesten Anlagen verbraucht. Infolgedessen ist das Hauptaugenmerk den zum Betrieb der Dampflokomotiven erforderlichen Brennstoffen zuzuwenden; die Vorschriften und Bestimmungen werden also in der Hauptsache den Lokomotivbrennstoffen angepasst sein, ohne dabei die besonderen Anforderungen, die an die Brennstoffe für die ortsfesten Anlagen zu stellen sind, ausser Acht zu lassen.

Lokomotivkohlen sollen im allgemeinen ohne Mischung verschiedener Marken (Gewinnungsstätten) und Sorten (Körnungen) bei Verfeuerung im Lokomotivkessel ausreichend Dampf erzeugen, ohne dabei übermässig viel Rauch zu entwickeln; sie dürfen bei gewöhnlicher Rostbeanspruchung nur wenig Flugasche und Flugkoks (Lösche) und selbst bei stärkster Feueranfachung kein Flugfeuer erzeugen. Die Schlackenbildung soll bestimmte Mengengrenzen nicht überschreiten, ihre Menge und Art muss derart sein, dass die Dampfentwicklung des Lokomotivkessels unter Voraussetzung der "üblichen Aufmerksamkeit und Sachkenntnis des Lokomotivpersonals" nicht beeinträchtigt wird, und die Roststäbe nicht in ungewöhnlicher Weise angegriffen werden. Auch übermässige Abzehrungen an den Feuerkisten dürfen nicht eintreten.

Diese Anforderungen erfüllt die Lokomotivkohle bei bestimmten physikalischen und chemischen Eigenschaften, deren Grenzwerte eingehalten werden müssen. Diese Grenzwerte stellen "Gütezahlen" dar, sie werden für: Gesamtfeuchtigkeit, Aschengehalt, Gehalt an brennbarer Substanz, unteren und oberen Heizwert auf Rohkohle bezogen, während: Gehalt an flüchtigen Bestandteilen und Schwefelgehalt auf Reinkohle berechnet wird. Für die Eigenschaften der Schlacke sind ihr Erweichungspunkt und ihr Schmelzpunkt im Zusammenhang mit der Temperatur in der Brennstoffschicht von

Interesse. Der Gehalt an flüchtigen Bestandteilen kann als wesentliches Merkmal für die Beurteilung der Brauchbarkeit einer Kohle als Lokomotivbrennstoff angesehen werden. Je nach dem Verwendungszweck der Kohlen im Lokomotivbetriebsdienst ist der Massstab, der an die Güte der Lokomotivkohlen gestellt wird, verschieden. Die schärfsten Anforderungen werden an die Lokomotivkohlen für den Dienst schnellfahrender Züge auf langen ohne Lokomotivwechsel zu durchfahrenden Strecken, sowie für den Dienst schwerbelasteter Güterzüge auf anhaltenden Steigungen gestellt. Die Anforderungen an die Stückgrösse (Sorte) bewegen sich nach zwei Richtungen. Da nur handbediente Lokomotivroste vorhanden sind, fordert der Feuerungsbetrieb einen bestimmten Mindestgehalt an Stücken vorgeschriebener Mindestgrösse. Reine Stückkohle, worunter man eine über Siebe von mindestens 80 mm Rundlochung sortierte Kohle versteht, wird vornehmlich für den wichtigsten Teil des Zugdienstes verwendet, da sie an Güte obenan steht, während die bestmelierte Kohle, die zur Hälfte aus faustgrossen Stücken bestehen soll, und die Würfelkohle im weniger angestrengten Zugdienst verfeuert wird. Nach der anderen Richtung hin ist ein möglichst kleiner Gehalt an Staub und Mull erwünscht und zwar nicht nur für die Verfeuerung, sondern auch für eine mit möglichst kleinen Stoff- und Güteverlusten erfolgende Beförderung und Lagerung.

Die Wirkung dieser vielseitigen Anforderungen an die Güte der Lokomotivkohle zeigt sich letzten Endes in der Auswahl von Kohlen, die je nach ihrem Verwendungszweck einen möglichst hohen feuerungstechnischen Wirkungsgrad ergeben.

Abnahme und Prüfung der Brennstoffe. Die Abnahme umfasst die Feststellung der äusserlich erkennbaren Eigenschaften der Brennstoffe, wie Gehalt an Bergmitteln, Körnung, Härte usw. Die Kohlenabnahmebeamten entnehmen nach eigenem Ermessen Proben beim Beladen der Wagen oder aus den fertig beladenen Wagen oder Kähnen, damit die äusserlich *nicht* erkennbaren Eigenschaften im Laboratorium festgestellt werden können. Die Proben werden in nichtrostenden Büchsen, die luftdicht verschliessbar sind (siehe Anlage 2) nach den Brennstofflaboratorien eingesandt mit einem Begleitzettel nach Anlage 3, der die Angaben über die Herkunft, Art und den Verwendungszweck des Brennstoffes, dem die Probe entnommen ist, enthält.

Brennstofflaboratorien und Laboratoriumsprüfung der Brennstoffe. Zur Untersuchung der von den Kohlenabnahmebeamten eingesandten Brennstoffproben auf ihre physikalischen und chemischen

Eigenschaften hat die Deutsche Reichsbahn ihre Wärmewirtschaftsbezirke mit eigenen Laboratorien ausgerüstet. Der Zweck der Brennstoffuntersuchungen ist, festzustellen, ob die angelieferten Brennstoffe den Anforderungen des Betriebes genügen. Kohlen, mit denen Brennstoffversuchsfahrten oder Feuerungsversuche in ortsfesten Anlagen vorgenommen werden, werden gleichfalls untersucht, um die Versuche auszuwerten und die Eigenschaften festzustellen, die die Verwendungsmöglichkeit für den gedachten Zweck festlegen. Chemische Untersuchungen müssen häufig erst dazu verhelfen, über die Verwendungsmöglichkeit und die Eigenart eines Brennstoffes Aufschluss zu erhalten. Die Güteprüfung in den Laboratorien erstreckt sich im allgemeinen auf die Feststellung der brennbaren Substanz durch Bestimmung von Aschegehalt und Gesamtfeuchtigkeit der Kohle im Anlieferungszustand, des Gehalts an flüchtigen Bestandteilen und des Heizwertes. Bei Kohlen, die erfahrungsgemäss leicht zur Verschlackung neigen, wird der Aschenschmelzpunkt und auch der Erweichungspunkt der Asche in elektrischen Röhrenöfen ermittelt. Schwefelbestimmungen werden, falls erforderlich, vorgenommen. Die meisten Laboratorien sind ausserdem mit Apparaten zur Vornahme der Elementaranalysen der Kohle ausgerüstet. Einigen Laboratorien sind Abteilungen für die Untersuchung von Gas, Öl und Teer angegliedert, um laufend deren Beschaffenheit zu überwachen. Aus der Anlage 4 geht die Einrichtung eines Laboratoriums hervor, das sich fast ausschliesslich mit der Untersuchung von festen Brennstoffen beschäftigt, während in Anlage 5 der Grundriss eines Laboratoriums dargestellt ist, das ausser der Untersuchung fester Brennstoffe noch in erheblichem Masse Untersuchungen flüssiger und gasförmiger Brennstoffe vornimmt.

Die wichtigste Grundlage zur Erzielung einwandfreier Prüfungsergebnisse im Laboratorium ist eine richtige Probenentnahme. Die Abnahmebeamten werden hierfür besonders ausgebildet. Entweder werden *Einzelproben* entnommen (Stichproben) oder ganze Lieferungen durch *Sammelproben* (laufende Überwachung) erfasst. Bei Einzelproben wird je nach der Art des Brennstoffes eine verschieden grosse Probemenge entnommen (bei grobstückiger Steinkohle z. B. 100 kg für einen oder je zwei Wagen) und diese nach der bekannten Diagonalmethode verkleinert. Bei der *laufenden Überwachung* werden Proben aus einer Anzahl von Wagen derselben Grube in ähnlicher Weise entnommen und *gesammelt*, bis die Lieferung beendet ist oder die Proben einer Liefermenge von etwa 200 t beisammen sind. Dann wird nach dem Diagonalverfahren

eine *Gesamtprobe* als Durchschnitt aller erfassten Lieferungen genommen. Die laufende Kohlenüberwachung ist auf Anlage 6 dargestellt.

Bei dem grossen Wert der Untersuchungen in den Brennstofflaboratorien wurde besondere Sorgfalt auf ihren weiteren Ausbau verwendet. Zur Zeit werden bei der Deutschen Reichsbahn-Gesellschaft jährlich über 11 000 Brennstoffuntersuchungen vorgenommen. Die Untersuchungsergebnisse werden in Zechenkarteien zusammengestellt und bilden wertvolle Unterlagen für die Auswahl der für die verschiedenen Verwendungszwecke geeignetsten Brennstoffe.

Brennstoffversuchsfahrten. Die Brennstoffprüfung im Laboratorium vermag zwar über die Zusammensetzung der Brennstoffe, ihren Heizwert und Aschegehalt Auskunft zu geben; sie gestattet jedoch noch kein Urteil über das Verhalten der Schlacken auf dem Rost und gegebenenfalls auch die höchstmögliche oder zweckmässigste Brenngeschwindigkeit. Die Laboratoriumsversuche sind daher durch Brennstoffversuchsfahrten mit der Lokomotive selbst zu ergänzen, welche die Prüfung der praktischen Brauchbarkeit und Wirtschaftlichkeit zum Ziel haben. Neben der schon erwähnten Feststellung der Brenngeschwindigkeit und Verschlackung ist der wichtigste Zweck dieser Fahrten die Ermittlung der betriebsmässigen Verdampfungsziffer. Die Brennstoffversuchsfahrten müssen, um ihr Ziel mit Sicherheit zu erreichen, gewisse Bedingungen erfüllen, die in den "Richtlinien für die Ausführung von Kohlenversuchsfahrten" für das Gebiet der Deutschen Reichsbahn-Gesellschaft festgesetzt sind. Hierzu gehört vor allen Dingen die Benutzung solcher Versuchsstrecken, die mit möglichst wenig Dampfpausen, also ohne längere Gefälle und dergleichen und mit gut ausgelasteten Zügen befahren werden, damit die Lebhaftigkeit der Verbrennung und die Dampflieferung möglichst konstant sind und also die Verbrennung mit der Dampflieferung des Kessels möglichst dauernd im Gleichgewicht ist. Auch sind Fahrten von möglichst grosser zeitlicher Dauer zu wählen, weil kurze Fahrten mit geringem Kohlenverbrauch eine erhebliche Unsicherheit in die Messungen hineintragen. Zu den Fahrten sind stets im guten Zustand befindliche Lokomotiven gleicher Gattung und aus dem gleichen Dienstplan zu wählen, damit die Vergleichsversuche mit dem Brennstoff nicht etwa durch die Verschiedenheit des Kesselwirkungsgrades oder die Auslastung der Züge in ihrem Ergebnis beeinträchtigt werden. Durch Auswahl besonders tüchtiger Personale ist weiterhin dafür zu sorgen, dass subjektive Fehler ausgeschaltet bleiben.

Die Richtlinien geben dann weiter eine Reihe Einzelvorschriften für die Wasser- und Kohlenmessungen als die Ausgangswerte der Verdampfungsziffer an; diese näheren Vorschriften sollen die notwendige Sorgfalt und Genauigkeit für die Feststellung der Betriebsstoffe sichern und infolge der an allen Stellen übereinstimmenden Erfahrungen die Ergebnisse der an verschiedenen Stellen vorgenommenen Versuche möglichst vergleichsfähig machen. Von den bei den Versuchsfahrten verwendeten Kohlen oder Briketts ist stets eine Durchschnittsprobe zu entnehmen und an das Laboratorium des Wärmewirtschaftsbezirkes zu senden.

Im Schlussabschnitt der Richtlinien werden dann noch einige Kriterien genannt, die äusserlich nicht misslungene, aber tatsächlich unwahrscheinliche oder unsichere Versuche auszuschalten gestatten, und die sich insbesondere auf den Kesselwirkungsgrad stützen, der sich aus den Aufschreibungen der Kohlenversuchsfahrten mittelbar entnehmen lässt, und der die bekannt gewordenen Höchstwerte der Kesselwirkungsgrade nicht überschreiten darf.

Bei dem wesentlichen Einfluss des Vorwärmers auf die Wärmebilanz der Lokomotive war der Hinweis erforderlich, dass man immer nur Lokomotiven mit *oder* ohne Vorwärmer, also bei den deutschen Lokomotivverhältnissen vorwiegend Lokomotiven mit Vorwärmer benutzt. Die zunächst gewonnene Bruttoverdampfungsziffer ist zweckmässig noch auf Normaldampf von einer Atmosphäre umzurechnen. Die Anlage 7 enthält den Vordruck, in den die Ergebnisse der Versuchsfahrten eingetragen werden, und der auch entsprechende Spalten enthält, um Begleitumstände des Versuchs, wie Rauchentwicklung bei der Verbrennung, Lebhaftigkeit der Dampferzeugung, u. a. m., festzulegen.

RICHTLINIEN FÜR DIE AUSFÜHRUNG VON KOHLENVERSUCHSFAHRTEN

1. *Allgemeines.* Die Kohlenversuchsfahrten dienen der Prüfung der Brauchbarkeit und Wirtschaftlichkeit von Lokomotivbrennstoffen und sollen die Brennstoffprüfung im Laboratorium ergänzen. Ihr Ziel ist neben der Feststellung sonstiger wichtiger Brenneigenschaften der Kohle (Brenngeschwindigkeit, Verschlackung) vor allem die Ermittlung der betriebsmässigen Verdampfungsziffer. Die Versuchsfahrten werden im Benehmen mit der örtlich zuständigen Reichsbahndirektion durch den Wärmewirtschaftsbezirk vorgenommen, entweder auf dessen eigene Veranlassung oder auf Wunsch der Kohlenbeschaffungsstelle oder einer Reichsbahndirektion. Die Versuchsfahrten sind unter Benutzung des vorgeschriebenen Vordrucks (siehe Anlage 7) auszuwerten.

Den Reichsbahndirektionen bleibt es unbenommen, sich durch Versuchsfahrten von der Eignung der Kohlensorten zu überzeugen, doch wird es sich im Zweifelsfalle empfehlen, solche Vorversuche durch die genaueren Kohlenversuchsfahrten zu ergänzen. Die bei solchen Vorversuchen gewonnenen

Ergebnisse sind von dem Wärmewirtschaftsbezirk bei der Abgabe seines Werturteils mit zu berücksichtigen.

2. *Ausführende Beamte.* Die Versuche werden jeweils von ein und demselben maschinentechnischen Beamten aus dem Bereich des Wärmewirtschaftsbezirks vorbereitet und überwacht; diesem Beamten ist nach Möglichkeit auch die Bearbeitung der Versuchsergebnisse zu übertragen. Die Begleitung aller Versuchsfahrten durch diesen Beamten ist erwünscht. Seine Befugnisse erstrecken sich indes nur auf die Messungen und Probeentnahmen; die *betriebliche* Durchführung der Fahrten ist Sache der örtlich zuständigen Reichsbahndirektionen.

3. *Auswahl der Versuchsstrecken und -züge.* Die Versuchsstrecken sind zweckmässig von der örtlich zuständigen Reichsbahndirektion unter dem Gesichtspunkt zu bestimmen, dass es sich um Strecken handeln soll, die mit möglichst wenig Dampfpausen (also ohne längere Gefälle und dergleichen) und mit gut ausgelasteten Zügen befahren werden.

Auch sind Fahrten von möglichst grosser zeitlicher Dauer zu wählen, da kurze Fahrten mit geringem Kohlenverbrauch eine beträchtliche Unsicherheit in die Messungen hineintragen. Die Genauigkeit der Versuchsergebnisse wird noch dadurch erhöht, dass man zu den Versuchsfahrten die gleiche Zugnummer und möglichst auch Züge mit gleicher Belastung auswählt und bei gleichen Witterungsverhältnissen fährt.

Züge mit Vorspann oder Schub kommen für die Fahrten nicht in Betracht.

4. *Auswahl der Lokomotiven.* Zu den Fahrten sind stets Lokomotiven gleicher Gattungen von der beteiligten Dienststelle der Reichsbahndirektion auszuwählen, und zwar solche von gutem Unterhaltungszustand. Handelt es sich um innerhalb kurzer Frist durchzuführende Vergleichsversuche, so wird im Interesse der Versuchsgenauigkeit zweckmässig für die Fahrtengruppen des Vergleichs jeweils dieselbe Lokomotive verwendet. Zu den Versuchen sind nur wenige, besonders tüchtige Personale heranzuziehen. Fahrten von ausgesprochenem Vergleichscharakter werden zweckmässig von dem *gleichen* Lokomotivpersonal ausgeführt.

Da die Genauigkeit der Wassermessung durch den Verlust von Schlabberwasser unter Umständen gestört werden kann, sind zu den Versuchsfahrten, wenn irgend angängig, Lokomotiven mit Speisewasservorwärmer zu verwenden. Auf jeden Fall müssen die Speisevorrichtungen in ordnungsmässigem Zustande sein.

5. *Vorbereitung und Durchführung der Versuchsfahrten und Messungen.* (*a*) Zu den wesentlichsten bei den Versuchen zu erfüllenden Forderungen gehört die einwandfreie Messung des Wasser- und Kohlenverbrauchs; Rost, Aschenkasten und Rauchkammer müssen vor Beginn der Fahrt sorgfältig gereinigt werden. Wenn es die Verhältnisse irgend gestatten, sind zur Gewinnung guter Durchschnittsergebnisse mehrere—etwa drei—vergleichsfähige Versuchsfahrten mit jeder Kohlensorte auszuführen.

(*b*) Die *Wassermessung* geschieht am besten mit der Messlatte; die Messung mit dem Tenderwasseranzeiger ist nicht zuverlässig genug. Der Tender ist für die Durchführung der Lattenmessung auf genau wagerechter und gerader Gleisstelle mit Messgefässen am besten von 250 zu 250 Litern auszulitern und die Latte entsprechend einzuteilen.

Die Verbrauchsmessungen müssen bei Beginn und Ende des Versuchs ebenfalls auf wagerechten und geraden Gleisstellen vorgenommen werden. Dabei

ist stets mit Hilfe einer Wasserwage die Schrägstellung des Wasserkastens festzustellen; die gemessene Wassermenge ist hiernach gegebenenfalls zu berichtigen. Die Forderung einer wagerechten und geraden Gleisstelle für die Messung muss auch deshalb erhoben werden, damit der Wasserstand im Lokomotivkessel bei Beginn und Ende der Fahrt zuverlässig festgestellt werden kann. In die Speisewasserleitung zum Vorwärmer einzuschaltende Wassermesser dürfen nur verwendet werden, wenn ihr einwandfreies Arbeiten besonders festgestellt ist.

(*c*) Die *Kohlenmessung* geschieht durch Abwiegen.

(*d*) Als Verbrauchszahlen haben nur diejenigen Mengen Wasser und Kohle in dem Versuchsergebnis zu erscheinen, die zur Deckung der während des Versuchs geleisteten Arbeit verbraucht werden.

Zur Erzielung vergleichsfähiger Ergebnisse der Kohlen- und Wassermessung und zur Vereinheitlichung des Verfahrens werden im folgenden die Ablesezeitpunkte festgelegt:

Ehe die Lokomotive an den Zug fährt, wird die Kohlenmenge geschätzt, die vor der Rohrwand liegt und die etwa von hier herrührende Asche aus dem Aschekasten entfernt. Diese Anfangskohlenmenge S_a beträgt je nach der Lokomotivgattung (Rostgrosse) etwa 150 bis 250 kg. Zugleich wird der Dampfdruck (etwa 7 bis 8 at) und der Wasserstand (etwa 4 cm über der Mutter) abgelesen und letzterer durch eine Marke bezeichnet. Diese 3 Werte müssen zu Anfang und Ende des Versuchs gleich sein oder gleich gemacht werden. Darauf wird das Feuer über den Rost gezogen, der Bläser angesetzt und die Lokomotive vor den Versuchszug gefahren. Von diesen Zeitpunkte ab wird Versuchskohle aufgegeben. Vor der Abfahrt des Zuges ist der Kessel aufzuspeisen und auf Hochstdruck zu bringen.

Anzustreben ist, die ganze Fahrt mit unveränderlichem Dampfdruck, Wasserstand und unveränderlicher Feuerschichthöhe und Überhitzung sowie gleicher Feueranfachung (Helligkeit des Feuers), bei Lokomotiven mit veränderlichem Blasrohr auch mit gleichbleibender Blasrohreinstellung durchzuführen.

Gegen Ende der Fahrt ist der Zustand der Lokomotive so einzurichten, dass das Feuer abgebrannt ist und der Dampfdruck sowie der Wasserstand die anfängliche Hohe von 7 bis 8 at bezw. 4 cm über der Mutter erreicht haben. Dampfdruck und Wasserstand werden sofort nach Schliessen des Reglers abgelesen. Dann wird das Feuer sorgfältig ausgeschlackt und an der Rohrwand neu angesetzt. Diese vorhandene Endkohlenmenge S_e muss gegebenenfalls durch Hinzufugung einiger Schaufeln Versuchskohle soweit ergänzt werden, dass die Anfangskohlenmenge S_a wieder vorhanden ist.[1]

Hiernach wird die von der Versuchskohlenmenge übriggebliebene Menge zuruckgewogen und der Kohlenverbrauch bestimmt.

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[1] *Anmerkung*. Wenn etwas Versuchskohle aufgegeben werden muss, um die Endkohlenmenge S_e der Anfangskohlenmenge S_a anzugleichen, so entsteht dadurch ein Fehler, dass diese Menge von höchstens 30 kg ihren vollen Wärmeinhalt besitzt, während der Brennstoff vor Beginn der Fahrt etwa schon zur Hälfte ausgebrannt ist, der Fehler beträgt aber bei einem Brennstoffverbrauch von rund 2 t höchstens

$$\frac{30 \cdot 0{,}5 \cdot 100}{2\,000} = 0{,}75\%$$

Diese Zahl ist aber an und für sich schon sehr klein und wird sich im Betriebe der Zahl 0 wesentlich nähern, so dass der Fehler ohne weiteres vernachlässigt werden kann.

Die da Messfehler bei der Feststellung des Kohlenverbrauchs wesentlich grössere sind als bei derjenigen des Wasserverbrauchs, so brauchen Feinheiten, wie Berücksichtigung des Schlabberwassers oder des Spritzwassers zum Kohlenmessen nur dann besonders berücksichtigt zu werden, wenn die Strahlpumpe besonders häufig betätigt wird oder ein besonders grosser Verbrauch des Spritzwassers bei trockenem Wetter und stark staubender Kohle zu erwarten ist. In solchen Fällen kann der Wasserverbrauch zum Messen der Kohle durch Benutzung des Tendereimers und der Schlabberwasserverbrauch aus der Zahl der Speisungen und dem festgestellten Durchschnittsverlust beim Ansetzen der Dampfstrahlpumpe ermittelt werden. Bei Lokomotiven mit Vorwärmer erubrigt sich die letzte Berichtigung.

Neben der so erfolgten Bestimmung der verbrauchten Kohlen- und Wassermenge sind noch die Brennstoffrückstande zu wiegen, nämlich die in die Rauchkammer ubergerissene Losche und die Rückstande im Aschkasten, getrennt nach Schlacke und Asche.

Dampfdruck- und Überhitzungstemperatur sind in Abständen von 10 Minuten bei geoffnetem Regler abzulesen, Tenderwasser- und, falls möglich, Speisewassertemperatur hinter dem Vorwarmer sind festzustellen. Das Pyrometer der Versuchslokomotive ist auf genaues Anzeigen zu prufen. Die Fahrt muss mit dem vorgeschriebenen Kesseldruck begonnen werden, Abblasen der Sicherheitsventile und Überreissen von Wasser ist zu vermeiden

(*e*) Erweisen sich im Laufe einer Fahrt Heizwert oder Kohlenmischung zur pünktlichen Beförderung des Zuges als nicht ausreichend, so ist auf die auf dem Tender sonst vorhandenen Kohlen zuruckzugreifen, um Verspatungen zu vermeiden. In diesem Falle bleibt nichts anderes ubrig, als die betreffende minderwertige Kohle in einem geanderten Mischungsverhältnis mit besserer Kohle zu verfeuern und eine erneute Versuchsfahrt anzusetzen

6 *Entnahme der Brennstoff- und Ruckstandeproben* Von den bei den Versuchsfahrten verwendeten Kohlen oder Briketts ist eine Durchschnittsprobe zu entnehmen und an die von dem Warmewirtschaftsbezirk bezeichnete Stelle einzusenden.

Wird als Versuchsbrennstoff eine Mischung verschiedener Sorten verwendet, so ist für die genaue Einhaltung des gewahlten Mischungsverhaltnisses und für möglichst gute Mischung der Sorten auch auf dem Tender zu sorgen Bei Verwendung einer solchen Mischung sind die Brennstoffproben stets den einzelnen Kohlensorten zu entnehmen und *ungemischt* der Untersuchungsstelle zuzusenden.

7. *Beurteilung der Ergebnisse.* (*a*) Es durfen nur solche Kohlenversuchsfahrten untereinander verglichen werden, die entweder mit Lokomotiven *mit* Vorwärmer oder *ohne* Vorwärmer ausgefuhrt worden sind. Da die Lokomotiven mit Vorwärmer überwiegen, wurde als Regelfall die Vorwärmerlokomotive unter Punkt 4 empfohlen. Nennenswert verschiedene Vorwärmung kann zu gewissen Fehlern Veranlassung geben Soweit nicht Einrichtungen zur genauen Bestimmung der Vorwärmertemperatur vorhanden sind, kann als guter Mittelwert eine Temperatur von 85°C angenommen werden. Das einwandfreie Arbeiten des Vorwärmers kann durch Messung der Temperatur des Kohlenspritzwassers dann festgestellt werden, wenn das Kohlenspritzwasser hinter dem Vorwärmer entnommen wird.

Das Hauptziel der Auswertung ist die Verdampfungsziffer bezogen auf Normaldampf von 1 at. Daneben ist aus dem Heizwert der Kohle und dem

Kohlenverbrauch die zugeführte Wärmemenge einerseits und aus dem Dampfverbrauch, dem Dampfdruck und der Überhitzung sowie der Temperatur des Speisewassers im Tender die nutzbare Wärme andererseits festzustellen. Der Quotient (letztere durch erste geteilt) bildet dann den Kesselwirkungsgrad im üblichen Sinne (also das Produkt aus dem Wirkungsgrad der Verbrennung im chemischen Sinne und dem Wirkungsgrad der Heizfläche bei vollkommener Verbrennung des Brennstoffes). Soweit die Versuche nicht mit Lokomotivgattungen vorgenommen sind, die wegen ihres ganz besonders hohen Kesselwirkungsgrades bekannt sind, muss der Versuch als zweifelhaft angesehen werden, wenn der Kesselwirkungsgrad einschliesslich des Vorwarmers grösser erscheint, als 0,85, da nur die besten bisher gemessenen Kesselwirkungsgrade diesen Betrag erreichen. Handelt es sich um Lokomotiven ohne Vorwärmer oder ist die Warmebilanz auf Grund der Speisewassertemperatur hinter dem Vorwärmer aufgestellt, so gilt der gleiche Zweifel fur Kesselwirkungsgrade uber 0,79. In diesen Fällen empfiehlt es sich, mit dem Reichsbahn-Zentralamt in Verbindung zu treten, das die Kesselwirkungsgrade der wichtigsten neueren Lokomotivgattungen kennt oder noch untersuchen wird.

Lagerung und Ausgabe der Brennstoffe. Bei der Besprechung der Anforderungen, welche die Deutsche Reichsbahn-Gesellschaft an die Lagerung und Ausgabe ihrer Brennstoffe stellt, sollen nur die festen Brennstoffe und zwar insbesondere die Lokomotivbrennstoffe berücksichtigt werden. Die Lagerhaltung und Ausgabe der Brennstoffe für die ortsfesten Anlagen gleicht derjenigen industrieller Kesselhäuser und Betriebe, so dass hierauf nicht besonders eingegangen werden soll.

Bei der Brennstoffversorgung der Lokomotiven hat man mit verhältnismässig wenig Brennstoffarten und -sorten zu tun, die in ziemlich einheitlich gestaltete Aufnahmebehälter—Kohlenraum der Tender und Tenderlokomotiven—von der Lagerstelle aus zu überführen sind. Hierbei sind folgende Forderungen, die sich teilweise einander widersprechen, gegeneinander auszugleichen und mit dem Endzweck möglichst hohen Gesamtwirkungsgrades, soweit als möglich, zu erfüllen:

(1) Die Gesamtkosten für die Bewegung der Mengeneinheit vom Gewinnungsort bis zur Verbrauchsstelle sollen möglichst klein gehalten werden.

(2) Der Brennstoff soll durch alle Bewegungsvorgänge nach Ziffer (1) zusammengenommen einschliesslich der dazwischen geschalteten Lagerung möglichst wenig an Güte (Brennwert, Wirtschaftswert) verlieren.

(3) Zur Erzielung höchster Betriebssicherheit soll die gleichmässige Brennstoffversorgung der Lokomotiven bei Stockungen aller Art in der Zufuhr auf längere Zeit hinaus unbedingt sichergestellt bleiben.

(4) Für jede einzelne Aufnahme von Brennstoffen in die Vorratsbehälter der Lokomotiven sollen die Sorten und die abgegebenen Gewichtsmengen zuverlässig bestimmt werden können.

Der Erfüllung dieser Forderungen, von denen (1) und (3) um so wichtiger werden, je weiter die Verbrauchsstelle von der Gewinnungsstätte entfernt ist, dienen folgende Massnahmen:

(Zu 1) Der Durchlauf grosser mechanisch zu leerender Ladeeinheiten (Grossraumgüterwagen) von den Kohlenrevieren bis zur Bekohlungsstelle der Lokomotiven und unmittelbare Bekohlung dieser aus den Wagen.

(Zu 2) Vermeidung jedes Zwischenumschlages (vergl. zu 1) sowie grösserer Fallhöhen bei der Bewegung der Kohlen.

(Zu 3) Schaffung von Vorrat- und Notlagern mit 4- bis 6-wöchigem Vorrat in günstiger Lage zu den Bekohlungsstellen.

(Zu 4) Sortentrennung in den Lagern (vergl. zu 3) und Ausrüstung der Bekohlungsanlagen mit zuverlässigen Verwiegeeinrichtungen.

Aus Vorstehendem ist, wie schon angedeutet, zu ersehen, dass nicht jeder der 4 Forderungen gleichzeitig restlos genügt werden kann. Denn einerseits widerspricht die Lagerhaltung (Ziffer 3) den Forderungen zu Ziffer 1 und 2, andererseits werden da, wo zur Erfüllung der Forderungen der Ziffern 2, 3 und 4 sehr erhebliche Baukosten erwachsen, die Gesamtkosten (einschliesslich Unterhaltung, Erneuerung und Schuldendienst) entgegen der Forderung der Ziffer 1 über Gebühr ansteigen.

Aus dem Widerstreit dieser Forderungen und ihrer Erfüllungsmöglichkeit im einzelnen, ferner aus der historischen technischen Entwicklung der Förderwesens und endlich aus der bei den einzelnen früher selbständigen Länderbahnen verschiedenen Gestaltung ihrer Bekohlungsanlagen hat sich der heute bei der Deutschen Reichsbahn-Gesellschaft bestehende Zustand herausgebildet. Es sind vielfach bereits neuzeitliche, sehr wirtschaftlich arbeitende Anlagen geschaffen worden, in älteren Bekohlungsanlagen und Kohlenvorratslagern muss jedoch bei einzelnen Bewegungsvorgängen noch Handarbeit aufgewendet werden.

Die Möglichkeit und Wirtschaftlichkeit durchgreifender Verbesserungen wird in einem Ausschuss von Fachmännern geprüft, dessen Arbeiten für künftige Um- und Neubauten neue Wege weisen.[2]

Es muss dabei berücksichtigt werden, dass die Lagerung und Abgabe der Kohle schon durch die Art der Anfuhr aus den Kohlen-

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[2] Siehe: Reutener "Neue Wege fur die Lokomotivbekohlung," Glaser's Annalen, 50. Jahrgang, Band 100, Heft 6 und 7.

revieren wesentlich beeinflusst wird. Diese vollzieht sich in weitaus überwiegendem Umfang in gewöhnlichen offenen Güterwagen (15 bis 20 t Ladefähigkeit); die Beförderung in Spezialwagen und, was für die Zukunft als besonders aussichtsreich gelten kann, in Pendelzügen mit Grossraumgüterwagen, bildet die Ausnahme.

Abgesehen von der Art der Zufuhr richtet sich die Ausgabe der Dienstkohle für die Lokomotiven auch nach der Grösse (Umschlagleistung) des Bahnhofes und nach seiner Lage zu seiner Umgebung und zum Gelände.

Wenn täglich nur wenige Lokomotiven auf einem Bahnhofe zu bekohlen sind, werden die Kohlen in Körben zu etwa 50 kg Inhalt ausgegeben. Wenn elektrische Arbeit zur Verfügung steht, benutzt man auch in diesen kleinen Anlagen schon einen feststehenden Säulendrehkran mit einer Ausladung von etwa 3,6 m und einer Tragfähigkeit von 1 500 kg. Die Kohle wird vom Lager oder unmittelbar aus dem Eisenbahnwagen mit der Schaufel in eiserne Hunde von 500 kg Inhalt geworfen. Diese Hunde werden durch den Drehkran gehoben und über dem Lokomotivtender durch Kippen entleert. Das Heben geschieht elektrisch, das Schwenken des Krans meistens von Hand. Diese Säulendrehkrane sind bei der Mehrzahl der Anlagen im Gebrauch, weil sie auch für grössere Tagesmengen geeignet sind.

In den letzten Jahrzehnten ist die Kohlenausgabe mit Greiferbetrieb aufgenommen worden. Der Greifer hängt entweder an einem fahrbaren Drehkran oder an einem fahrbaren Portalkran. Die fahrbaren Drehkrane laufen meistens auf regelspurigen Gleisen, sind aber auch vereinzelt für Breitspur von 2,5 bis 3 m gebaut. Die regelspurigen fahrbaren Drehkrane haben den Vorteil der Freizügigkeit, so dass ein solcher Kran als Reserve für mehrere Lokomotivbahnhöfe bereitgehalten werden kann und auch nicht an eine beschränkte Arbeitsstelle gebunden ist. Der Greiferbetrieb brachte den Vorteil, dass grössere Kohlenlager ohne Handarbeit durch den Greifer bestrichen werden und dass die Kohle unmittelbar aus den Eisenbahnwagen auf den Tender gebracht wird. Um einerseits die Abfertigung der Lokomotive noch mehr zu beschleunigen, andererseits eine zeitweise Stillegung der Krananlagen (z. B. zur Nachtzeit oder zur Vornahme kleinerer Ausbesserungsarbeiten) ohne Störung des Bekohlungsgeschäftes zu ermöglichen, stattet man die Bekohlungsanlage mit feststehenden oder fahrbaren Kohlenbunkern aus, die entweder aus einer grösseren Anzahl von Taschen mit je 1 bis 3 t Inhalt oder auch nur aus wenigen grossen Taschen von je 15 bis 30 t Inhalt bestehen.

In geeignetem Gelände oder, wenn bei dem Bau des Lokomotivbahnhofes genügend Bodenmassen zur Verfügung standen, hat man Schüttbühnen eingerichtet, auf denen die Kohlen mittels Kippkarren von etwa 500 kg Inhalt an die Vorderkante gefahren und dort auf den Tender abgestürzt werden.

Vereinzelt sind unter besonderen Verhältnissen noch Anlagen anderer Bauart (z. B. hochstehende, durch ein Becherwerk bediente Grossbunker mit Zubringerseilbahn u. a.) geschaffen worden.

Die unentbehrlichen Vorrat- (Not-) Lager sind fast ausschliesslich auf den Lokomotivbahnhöfen selbst oder nur für den Ortsbedarf angelegt. Sie sind bei allen grösseren Anlagen mit mechanischen Fördereinrichtungen (z. B. fahrbaren Portalkranen, Greiferdrehkranen, Absturzanlagen usw.) ausgestattet, wobei diese Anlagen meist auch der Kohlenabgabe an die Lokomotive dienen. In einzelnen Fällen, insbesondere an Schiffsumschlagsplätzen, finden sich umfangreiche mit Verladebrücken ausgerüstete Vorratslager für grössere Versorgungsbezirke zum Ausgleich unvermeidlicher Schwankungen in der Anfuhr und zur Vorhaltung grösserer Reservebestände für den Fall von Streik usw. Als Bindeglied zwischen Vorratslager und Ausgabestellen sind hier teilweise Wagen besonderer, den Umschlagseinrichtungen der Abgabestellen angepasster Bauart (z B. Trichterwagen), sonst aber offene Kohlenwagen gewöhnlicher Bauart, in Verwendung.

Von dem früheren Verfahren, die Kohlen in Dauerlagern zu stapeln, ist man wegen der erheblichen Kosten und wegen Wertminderung durch langes Lagern auch bei ganz grossen Vorratslagern abgekommen. Die Deutsche Reichsbahn-Gesellschaft beschränkt heute das Lagern der Kohle im allgemeinen auf Zeiträume bis zu 1 Jahr und sorgt für periodischen Umtrieb. Soweit möglich, werden die verschiedenen Arten und Sorten getrennt und nur solange gelagert, dass sie unter den Witterungseinflüssen nicht unverhältnismässig stark leiden. Hierüber sind besondere Versuche mit einer Reihe gebräuchlicher Lokomotivkohlensorten der verschiedenen Arten im Gange. Die Lagerung erfolgt an gut entwässerbaren Stellen in eingefriedeten, vielfach mit festem Boden versehenen und durch Gänge unterteilten Bansen, bei Presskohlen in Stapeln, grundsätzlich im Freien und ohne Bedachung. Als normale Lagerhöhe können etwa 3 m angenommen werden.

Zur mengenmässigen Überwachung der Bestände werden die Haufen oder Stapel mit Schildern über Menge, Herkunft, Art, Sorte und Tag der Einlagerung versehen. Eine ständige Überwachung der Temperaturen zum Schutze gegen Selbstentzündung wird bei

der niedrigen Stapelhöhe im allgemeinen nicht für erforderlich gehalten. Bei besonders grossen oder hochgestapelten Lagern oder wenn es sich um leichtentzündliche Kohlenarten und Kohlengemische handelt, wird häufig eine Temperaturkontrolle—sei es durch Einrammen unten geschlossener Rohre mit eingelassenem Thermometer oder durch selbsttätige Temperaturfernmeldeapparate—geschaffen

Früher war die Feststellung der abgegebenen Kohlenmengen lediglich auf die Raummessung (nach dem Inhalt der Fördergefässe) beschränkt; jetzt erfolgt diese Kontrolle bei den wichtigeren Kohlenausgabestellen durch planmässigen Einbau von Verwiegeeinrichtungen, die eine genaue Gewichtsbestimmung der an die Lokomotive abgegebenen Kohlenmengen ermöglichen. Dadurch werden zuverlässige Unterlagen geschaffen, einerseits für die zur Stoffbuchführung und Bilanzierung erforderliche Bestimmung der Grösse der Lagerbestände, andererseits für die Festsetzung der im ganzen Gebiet der Deutschen Reichsbahn-Gesellschaft jetzt eingeführten Brennstoffersparnisvergütung im Lokomotivdienst auf der Grundlage der Leistung und des Brennstoffverbrauches.

VERWENDUNG DER BRENNSTOFFE

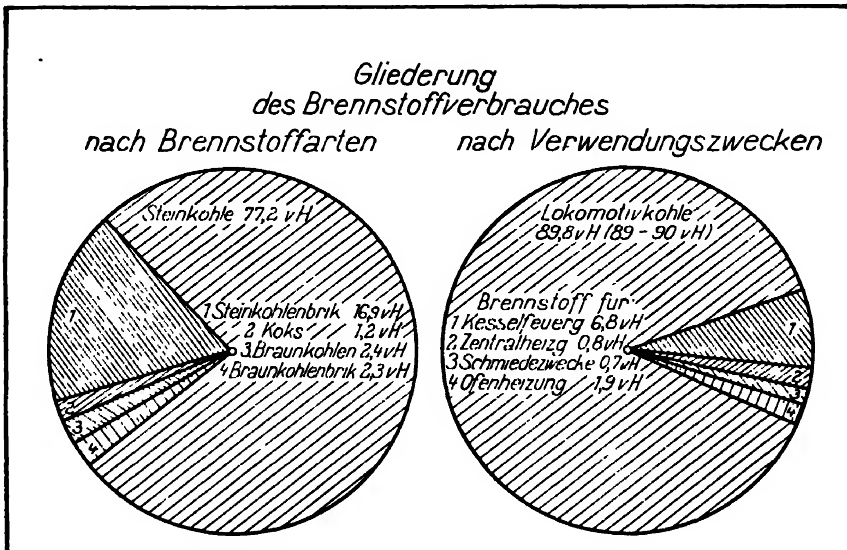
Verwendungszwecke und ihre Anteile am Gesamtverbrauch der Deutschen Reichsbahn. Entsprechend dem Wesen der Eisenbahnunternehmungen, deren eigentliche Aufgabe die Zugförderung ist, wird von dem gesamten Brennstoffverbrauch die bei weitem überwiegende Menge für die *Feuerung der Lokomotiven* verwendet, nämlich rund 90 v. H. des gesamten Brennstoffverbrauches.

An zweiter Stelle kommen die *ortsfesten Kesselanlagen* für die Erzeugung von Hochdruckdampf in Betracht, die in den Ausbesserungswerken den Dampf für die Fabrikation sowie für die Heizung der Werkstätten, in den Betriebsanlagen den Dampf für die Vorheizung der Züge, die Reinigung und Desinfektion der Wagen und von Fall zu Fall auch für die Heizung in der Nähe gelegener Verwaltungsgebäude liefern. In diesen Anlagen überwiegt der von dem Klima und der Witterung abhängige Verwendungszweck, d. h. die Erzeugung von Heizdampf. Im ganzen werden in den ortsfesten Hochdruckanlagen etwa 7 v. H. des gesamten Brennstoffverbrauches verwendet.

Nur geringe Bedeutung hat der Menge nach der Verbrauch von Brennstoffen für *Fertigungszwecke* bei der Wiederherstellung der Fahrzeuge (etwa 0,7 v. H.), wobei allerdings hervorgehoben werden

muss, dass diese Angaben sich nur auf feste Brennstoffe beziehen, während gerade für die genannten Zwecke auch flüssige und gasförmige Brennstoffe in grösserem Umfange benutzt werden.

Schliesslich hat der Brennstoffverbrauch für die *Heizung der Räume* (Verwaltungsgebäude, Diensträume, Stellwerke, Dienstwohnungen und dergl.) eine nicht geringe Bedeutung, da die Eigenart der Eisenbahnunternehmungen eine erhebliche Zahl derartiger Anlagen bedingt. Der Verbrauch in *Zentralheizungen*, die bei Gebäuden von einem gewissen Rauminhalt an aus wirtschaftlichen Gründen, bei Stellwerken aus betrieblichen Gründen, angewendet werden, wird auf etwa 0,8 v. H. geschätzt; der Verbrauch in den zahlreichen *Einzelheizungen*, die sich infolge der Zersplitterung der Betriebsstellen im Eisenbahnwesen vorfinden, ist etwa 1,9 v. H.



Die Gliederung des Gesamtbrennstoffverbrauches der Deutschen Reichsbahn-Gesellschaft nach Verwendungszwecken ist in vorstehendem Diagramm wiedergegeben.

Auswahl der Brennstoffe für den Verwendungszweck. Für Unternehmungen mit vielseitiger Verwendung der Brennstoffe hat die Auswahl der Brennstoffe besondere Bedeutung; diese wird noch erhöht für den Fall, dass verschiedenartige Brennstoffe für den gleichen Zweck zur Verfügung stehen.

Bei der Auswahl der Brennstoffe sollte der Gesichtspunkt der grössten Wirtschaftlichkeit massgebend sein, d. h. derjenige Brennstoff ist zu wählen, der die angestrebte Leistung mit dem geringsten Geldaufwand ermöglicht. Neben den Kosten für die Wärmeeinheit

ist hierbei auch der Einfluss des Wirkungsgrades der zu verwendenden Einrichtungen, des für sie erforderlichen Gesamtbetriebsaufwandes (Betrieb, Unterhaltung und Kapitaldienst, d. i. Verzinsung und Abschreibung) und der Güte des Erzeugnisses zu berücksichtigen. Es treten dabei feste, flüssige und gasförmige Brennstoffe untereinander und ihrerseits mit dem elektrischen Strom als Wärmeerzeuger in Wettbewerb.

Daraus geht hervor, dass bei Eisenbahn-Unternehmungen, die sich über weite Landesgebiete erstrecken, in denen auf der Grundlage der natürlichen Brennstoffvorkommen verschiedene Wärmepreise vorhanden sind, die Auswahl der Brennstoffe an den verschiedenen Orten von Fall zu Fall getroffen werden muss und hierbei auch die zu verwendenden Einrichtungen entsprechend gewählt werden müssen. Andererseits kann aber auch die Auswahl der Brennstoffe von den einmal vorhandenen Einrichtungen abhängig sein derart, dass für diese Einrichtungen der wirtschaftlichste und geeignetste Brennstoff gefunden werden muss.

Auf der Grundlage dieser engen Beziehungen zwischen Verwendungsart, Feuerungseinrichtung und Brennstoff gilt für das Eisenbahnwesen folgendes:

(*a*) Der hauptsächlichste Verwendungszweck ist die Verfeuerung der Brennstoffe im *Lokomotivkessel.* Sein Betrieb ist dadurch gekennzeichnet, dass der Feuerraum allseitig gekühlt ist (Wärmespeicherung auf der Höhe der für die Verbrennung nützlichen Temperatur nur im Feuerschirm), dass eine sehr grosse Brenngeschwindigkeit (hohe Rostbelastung) erforderlich ist und erhebliche Belastungsschwankungen auftreten. Hieraus folgt, dass der Gasgehalt der Kohle nicht zu klein sein darf (wegen der sicheren Entzündung ohne zu hohe Feuerschicht), dass er aber auch nicht zu hoch sein darf (mit Rücksicht auf die restlose Verbrennung der Gase auf verhältnismässig kurzem Flammenwege und auf die ungünstige Beeinflussung der Verbrennung durch die kühlen Kammerwände), dass ferner der Grusgehalt nur dann in höherem Masse zulässig ist, wenn die Kohle backende Eigenschaften hat, wodurch auch die feinkörnigen Bestandteile im Kohlenbett festgehalten werden, dass aber bei nichtbackenden, insbesondere auch bei mageren Kohlen ein hoher Flugkoksverlust eintreten muss (Einfluss der hohen Brenngeschwindigkeit). Leicht zerfallende Brennstoffe führen infolge der Schüttelbewegung des Rostes zu Verlusten im Aschekasten und zu Flugkoksverlusten; es ist daher eine gewisse Festigkeit der Lokomotivkohle erwünscht, die auch die Verluste bei der Lagerung und Verladung herabsetzt.

Der Heizwert der Kohle soll mit Rücksicht auf die hohe Wärmeleistung, die je m² Rost gefordert wird, möglichst hoch sein, die Ballaststoffe—Wasser und Asche—müssen daher in verhältnismässig engen Grenzen liegen. Die Asche soll einen möglichst hohen Schmelzpunkt haben, damit auch bei starker Beanspruchung ein Verschlacken des Rostes nach Möglichkeit vermieden wird.

Im Rahmen dieser Bedingungen wird sich die Auswahl der für das Eisenbahnwesen wichtigsten Brennstoffe, der Lokomotivkohle, nach den zur Verfügung stehenden Sorten zu richten haben, sei es, dass diese im Inlande selbst gewonnen oder aus anderen Ländern eingeführt werden.

In Deutschland und für die Deutsche Reichsbahn kommen hiernach in erster Linie im Westen die Fettkohlen des Ruhrgebietes (in geringerem Masse die Esskohlen mit etwas niedrigerem und Gasflammkohlen mit etwas höherem Gasgehalt, und zwar als Förderkohlen, durch Stücke aufgebesserte Förderkohlen oder reine Stückkohlen), im Osten oberschlesische und niederschlesische Förder- und Stückkohlen sowie Steinkohlenbriketts (Presskohlen), die aus dem bei der Steinkohlenförderung anfallenden Staub hergestellt werden, in Frage.

Bei der in Entwicklung befindlichen Kohlenstaubfeuerung sind die Bedingungen für die zu verwendende Kohlensorte infolge der starken Zerkleinerung (Mahlung) nicht so scharf abgegrenzt wie bei der Rost-Feuerung; hier kann Staub aus getrockneter Braunkohle, aus geschwelter Braunkohle und aus Steinkohle mittleren und hohen Gasgehaltes in Betracht gezogen werden.

(*b*) Wesentlich anders ist die Auswahl der Brennstoffe für die *ortsfesten Kesselanlagen* zu beurteilen, die im Gegensatz zu der Gleichartigkeit der Feuerungseinrichtungen bei den Lokomotiven sehr verschiedene Bauarten aufweisen. Andererseits sind aber auch die Bedingungen der Betriebsführung sowohl hinsichtlich der Rostbeanspruchung wie hinsichtlich der Grösse und Ausbildung der Feuerungsräume wesentlich günstiger als bei der Lokomotive. Die Verwendung der für den Lokomotivbetrieb erforderlichen hochwertigen Brennstoffe kann daher hier vermieden werden. Allgemein gesagt wird sich sonach die Auswahl der Brennstoffe auf diejenigen Sorten zu erstrecken haben, die infolge ihrer Körnung, ihres Gasgehaltes oder niedrigeren Heizwertes als minderwertig bezeichnet und gering bewertet werden. Gerade bei derartigen Sorten ist die Eigenart der Feuerungseinrichtung von besonderem Einfluss; die Wirtschaftlichkeit der Brennstoffe

muss daher hier—wie bereits allgemein dargestellt—unter Einbeziehung sämtlicher Nebenumstände ermittelt werden.

Als minderwertige Brennstoffe in diesem Sinne kommen in Deutschland Rohbraunkohle, kleinere Körnungen und Grus von mageren Kohlen, Esskohlen und Gasflammkohlen (im Westen), Staubkohlen (im Osten), Pechkohlen (im Süden), ferner Koksgrus und Rauchkammerlösche in Betracht. Bei Mangel an Sondereinrichtungen für die Verfeuerung dieser Brennstoffe ist die Mischung mit höherwertigen Brennstoffen in Betracht zu ziehen.

Braunkohlenbriketts sind nur in gewissen Grenzen von den Braunkohlenrevieren wirtschaftlich verwendbar, die einerseits durch den Wettbewerb mit der Rohbraunkohle, andererseits durch den Wettbewerb mit der Steinkohle gegeben sind. Neuerdings haben sich diese Grenzen erweitert durch die der Verfeuerung vorangehende Schwelung der Briketts, deren effektiver Preis hierbei durch die Gewinnung des Teeres verbilligt wird.

(*c*) Für die *Fertigung in den Werkstätten* werden Brennstoffe unmittelbar hauptsächlich zum Erwärmen und Schmelzen von Metallen benötigt. Für das *Schmelzen von Eisen* im Kupolofen wird Zechenkoks (Schmelzkoks) verwendet, der möglichst niedrigen Schwefel- und Aschegehalt und hohe Festigkeit haben soll und dessen Körnung durch die Bauart des Ofens bedingt ist. Unter Umständen kommt auch Torfkoks hierfür in Frage. Die wirtschaftliche Bewertung richtet sich hierbei nicht nur nach dem Verbrauch an Koks für 1 t geschmolzenes Eisen, sondern auch danach, ob das niedergeschmolzene Eisen leicht giessbar ist (Leichtflüssigkeit) und die von ihm geforderte Festigkeitseigenschaften durch den Einfluss des Kokses nicht beeinträchtigt werden (Brüchigkeit des Eisens, verhältnismässiger Ausschuss).

Das *Schmelzen von Legierungen* wird in Tiegeln vorgenommen, die mit Koks, oder in tiegellosen Öfen, die unmittelbar mit Gas oder mit Öl beheizt werden. Zur Erzielung der notwendigen Temperaturen bedarf es eines hochwertigen Kokses oder eines hochwertigen Gases, erforderlichenfalls der Vorwärmung der Verbrennungsluft, die auch bei Ölfeuerungen von Vorteil ist.

Für *Erhitzung von Metallen in Öfen* wird vielfach Gas verwendet, das entweder in mit dem Ofen zusammengebauten Halbgasfeuerungen oder zentral in besonderen Anlagen erzeugt oder fremden Gasleitungen entnommen wird. In den beiden ersten Fällen bedarf es zur Erzielung der erforderlichen Temperaturen der Vorwärmung der Luft, die fast ausschliesslich mittels der Abwärme der Öfen erzielt wird. Als Brennstoff für die Halbgas- oder

selbständigen Gasgeneratoren kommen Braunkohlenbriketts, Gasflammkohle oder Koks in Frage, daneben können die bessere Beherrschung der Temperaturen, das rasche Erhitzen und auch die Ersparnis an Raum und Bedienungspersonal sowie grössere Sauberkeit häufig zur Verwendung von Öl und Leuchtgas zur Beheizung von Öfen veranlassen, auch wenn diese Brennstoffe einen höheren Wärmepreis haben als feste Brennstoffe. Von besonderem Vorteil kann diese Beheizungsart für solche Vorgänge sein, bei denen der Ablauf des Erwärmungsvorganges genau vorgeschrieben und das behandelte Gut hochwertig ist, wie z. B. beim Härten und Anlassen.

In den offenen *Schmiedefeuern*, deren Verwendung nach Möglichkeit eingeschränkt wird, wird die Wärme auf das zu erhitzende Eisen unmittelbar durch Einhalten desselben in einen Kohlenhaufen übertragen. Die Kohle muss daher so beschaffen sein, dass die Wärme im Innern zurückgehalten wird; sie muss zur Erzielung dieses Zweckes kleinkörnig und backfähig sein, bei mittlerem Gasgehalt einen guten Koks bilden und soll nicht zuviel Asche und möglichst keinen Schwefel enthalten.

Die Wirtschaftlichkeit der gewählten Brennstoffe wird an dem Verbrauch für 1 t durchgesetztes Eisen gemessen; dieser Wert hängt allerdings stark von der Güte der Einrichtungen und der Betriebsführung ab. Schliesslich kommt noch für diejenigen Fälle, in denen vollkommen schwefelfreier Brennstoff gefordert werden muss, wie z. B. bei der Behandlung von Kupfer, sowie bei der Vorwärmung von zu schweissendem Guss oder Stahlguss, die Verwendung von Holzkohle oder Torfkoks in Frage.

(*d*) Die *Heizung von Wohn- und Diensträumen*, die bei grossen Unternehmungen einen erheblichen Umfang hat, erfordert ebenfalls eine besonders aufmerksame Auswahl der Brennstoffe. Für die *Zentralheizungen* üblicher Bauart wird in erster Linie gasarmer Brennstoff, nämlich Steinkohlenkoks, verwendet. Zu fordern ist, dass dieser Koks genügend fest ist, wenig Grus enthält und dass sein Asche- und Wassergehalt begrenzt ist. Für den vorliegenden Zweck genügt in den meisten Fällen der Koks aus den Gasanstalten; nur in besonderen Fällen (hohe Beanspruchung der Anlagen, Beschränktheit der Lagerräume, Preisgestaltung zugunsten des Schmelzkoks) wird auch Schmelzkoks verwendet. In der Nähe der Braunkohlengebiete bietet die Verwendung von Braunkohlenbriketts, für die jedoch die Zentralheizungskessel besonders ausgebildet sein müssen, wirtschaftliche Vorteile. Die Ölfeuerung für derartige Anlagen hat sich in Deutschland noch nicht eingebürgert,

die Gasheizung wird von einer Herabsetzung der bisher üblichen Gaspreise abhängen.

Die *Einzelheizungen* sind zum Teil auf Braunkohlenbriketts angewiesen, wofür meist Kachelöfen mit oder ohne Rost oder auch besondere mit Zuführung von Sekundärluft ausgerüstete eiserne Öfen benutzt werden. In der Nähe der Steinkohlenreviere werden vorzugsweise magere Kohlen (Anthrazit in Dauerbrennern) verwendet. Für die Gasheizung gilt das gleiche wie für die Zentralheizungsanlagen bemerkt wurde.

Ausnutzung der Brennstoffe in den Lokomotiven. Soweit unter Ausnutzung der Brennstoffe in Lokomotiven im wesentlichen zu verstehen ist, dass eine Statistik über den Kohlenverbrauch der Lokomotiven geführt und ausgewertet wird, geschieht das in folgender Weise.

Für jede Lokomotive überhaupt werden einmal die empfangenen Kohlen in t aufgeschrieben, andererseits ihre Leistung in Lokkm bezw. Bruttotkm. Diese Zahlen werden dazu benutzt, um für jeden Dienstplan eines Bahnbetriebswerkes oder einer Lokomotivstation den Kohlenverbrauch in t für 1 000 Lokkm (und künftig auch für eine Million Bruttotkm) zu errechnen und in den betreffenden Spalten der Lokomotivstatistik vorzusehen. Der durchschnittliche Verbrauch eines solchen Dienstplanes spielt eine Rolle bei der Bemessung der Kohlenprämie; Lokomotiven werden dann als mangelhaft in ihrer Kohlenausnutzung zu bezeichnen sein, wenn sie von dem durchschnittlichen Verbrauch wesentlich nach oben abweichen. Die Gründe dieser Abweichung festzustellen und nach Erkenntnis zu beseitigen, ist Sache der betriebsführenden Reichsbahndirektion und ihrer Organe.

Neue Lokomotiven werden nebenher noch bis zu ihrer ersten Hauptausbesserung vom Reichsbahn-Zentralamt verfolgt. Dem Reichsbahn-Zentralamt wird der kilometrische Kohlenverbrauch und der Verbrauch für das Bruttotkm angegeben. Im allgemeinen werden immer mehrere Lokomotiven einem Betriebswerk überwiesen, so dass Vergleiche zwischen diesen Lokomotiven, weil sie in einem Dienstplan laufen und mit der gleichen Kohle versorgt werden, leicht möglich sind. Das Laufen in einem Dienstplan, also die Versorgung stets mit der gleichen Kohle, gestattet überhaupt allein den Vergleich mehrerer Lokomotiven, solange nicht bekannt ist, dass gleiche Lokomotiven auf anderen Stationen in gleich schwerem Dienst und mit gleichwertiger Kohle versorgt laufen. Handelt es sich bei den neuen, vom Reichsbahn-Zentralamt verfolgten Lokomotiven um solche bereits bestehender Gattungen, so

ist die Verfolgung der Güte dieser Lokomotivlieferung durch Vergleiche mit den vorhandenen gleichartigen Lokomotiven einfach. Handelt es sich dagegen um neue Gattungen, so ist die Massnahme der Stationierung mehrerer Lokomotiven einer neuen Gattung an einem Stationsort sogar für eine vergleichsweise Beurteilung der Lokomotiven unentbehrlich.

Für die genaue Feststellung des Kohlenverbrauches für die Leistungseinheit und also für die Feststellung des Wohlgelungenseins einer neuen Lokomotivgattung oder für die Gewinnung von Anhaltspunkten für die noch zu erstrebenden Verbesserungen, sind endlich die Versuchsfahrten des Lokomotivversuchsamtes Grunewald von höchstem Wert, weil hier die Verbrauchszahlen auf eine ganz exakte Einheit, nämlich die PSh, bezogen werden muss und besondere Massnahmen (Lokomotiven mit Gegendruckbremse) zur Verfügung stehen, um den Beharrungszustand beliebig lange durchhalten zu können. Es ist hier auch wegen der Bezugnahme auf die exakte Arbeitseinheit das gegenseitige Verhalten der Lokomotivgattungen ohne weiteres nachprüfbar. Andererseits ist es aber sehr schwierig, die Verbrauchszahlen dieser auf genaue Weise gewonnenen Verbrauchszahlen der wissenschaftlichen Versuche auf die normale Betriebsstatistik zu übertragen, da ein derart reiner Beharrungszustand im praktischen Betriebe kaum jemals auftritt und ausserdem die Verbrauchszahlen des praktischen Betriebes noch die Anheizkohlen und den während des Bereitschaftsdienstes verbrauchten Brennstoff enthalten.

Ausnutzung der Brennstoffe in ortsfesten Anlagen. Die ortsfesten Kesselanlagen liefern Dampf fast ausschliesslich fur *Heizzwecke* (zur Vorheizung von Personenzügen und für die Heizung grosser Räume); dadurch ist die Belastung dieser Anlagen als eine vom Klima und von der Witterung abhängige gekennzeichnet, die nur während des Winterhalbjahres auftritt, während dieser Zeit tageweise mit dem Heizungsbedarf schwankt, während der einzelnen Tage jedoch ziemlich gleichmässig ist. Die während des ganzen Jahres zu liefernde Dampfmenge wird für die Fabrikation in den Ausbesserungswerken und zur Warmwasserbereitung für Desinfektion der Wagen, für Waschanstalten, Badeanstalten und dergl. benutzt und hat geringere Bedeutung.

Die Ausnutzung der Brennstoffe in den Heizanlagen hängt—wie bei jeder Kesselanlage—von der Belastung ab, und da diese in dem gekennzeichneten Sinne schwankt, hat die Verteilung der gesamten im Höchstfalle erforderlichen Heizfläche auf Kesseleinheiten von zweckmässiger Grösse wesentlichen Einfluss. Eine gute Belastung

der Heizfläche und damit eine gute Ausnutzung der Brennstoffe muss dann durch Anpassung der in Betrieb zu nehmenden Kesseleinheiten an die Aussentemperatur erreicht werden.

Allgemein gültige Zahlenwerte lassen sich für die Heizanlagen nicht angeben, da die an sie gestellten Anforderungen und insbesondere auch die Bedarfsschwankungen je nach ihrer klimatischen Lage sehr verschieden sind. In einem mittleren Klima—wie in der norddeutschen Tiefebene—ist die monatliche Höchstbelastung etwa das 2½-fache der durchschnittlichen Belastung. Aus diesem Beispiel geht hervor, dass zur Verringerung des Kapitaldienstes Kesselbauarten gewählt werden müssen, die—erforderlichenfalls unter vorübergehender Benutzung hochwertiger Brennstoffe—während der verhältnismässig kurzen Lastspitzen stark beansprucht werden können.

Die Ausnutzung der Brennstoffe ist im allgemeinen dort, wo die Kessel mit Frischwasser gespeist werden müssen, da kein Kondensat zurückfliesst, wie bei den Zugvorheizungen, durch die Anwendung von Rauchgasvorwärmern besser, als bei solchen Anlagen, in denen das Kondensat in den Kessel zurückfliesst, insbesondere bei Hochdruckumlaufheizung, bei der es nahezu die Dampftemperatur aufweist. In letzterem Falle müssen besondere Mittel zur Ausnutzung der Abwärme angewendet werden.

Während bei reinen Heizanlagen mit Hochdruckdampf das Druckgefälle zum Teil bei der Überwindung grösserer Entfernungen und schliesslich an den Verteilungsstellen durch künstliche Druckminderung vernichtet wird, wird es bei *Heizkraftwerken* zur Erzeugung von mechanischer oder elektrischer Energie ausgenutzt. Der Dampfdruck nach der Krafterzeugung muss für die technischen Einrichtungen der Heizanlagen noch genügen; er wird in einem Zwischenstadium bei der Krafterzeugung abgezapft oder am Ende der Krafterzeugung entnommen. Die Ausnutzung der Brennstoffe in diesen Anlagen ist wesentlich besser, weil die Heizanlage in ähnlicher Weise, wie ein Kondensator, hinter die Kraftmaschine geschaltet ist, wobei zugleich die Verdampfungswärme des Dampfes den Heizungszwecken nutzbar gemacht wird.

Im Eisenbahnbetrieb bietet sich in erster Linie in den Ausbesserungswerken Gelegenheit für eine derartige Verbindung der Krafterzeugung mit den Heizanlagen. Bei dem üblichen Verhältnis des Kraftbedarfes und Wärmebedarfes in diesen Anlagen ist es möglich, in mittlerem Klima mindestens während der 5 Wintermonate mit dem für Heizung erforderlichen Dampf vorher die erforderliche Kraft zu erzeugen; für den Rest des Jahres dagegen muss der

Bedarf an elektrischer Arbeit durch Fremdbezug oder durch Betrieb der Anlage mit Kondensation gedeckt werden, wobei jedoch mit Rücksicht auf den verhältnismssig kleinen Kraftbedarf der Sommerbetrieb finanziell und wärmewirtschaftlich gegenüber Grossanlagen nicht wettbewerbsfähig ist.

Ausnutzung der Brennstoffe in der Fertigung. Auf dem Gebiete der Fertigung werden Brennstoffe hauptsächlich zur Erhitzung und zum Schmelzen von Metallen verwendet. Die Ausnutzung der Brennstoffe ist hierbei in hohem Masse von der Inanspruchnahme der Einrichtungen abhängig, nicht nur hinsichtlich des ausreichenden Durchsatzes in der Zeiteinheit, sondern auch hinsichtlich der Unterbrechungen des Betriebes durch die Schichtzeit. Alle in Frage kommenden Einrichtungen besitzen Wärmespeicher in Form von feuerfestem Material, die bei der Inbetriebnahme aufgeheizt werden müssen und deren Wärme bei der Ausserbetriebnahme zum grössten Teil verloren geht.

In den Eisenbahnwerkstätten sind im allgemeinen die Betriebsbedingungen für die Ausnutzung der Brennstoffe nicht günstig, weil meistens nur in einer Schicht gearbeitet wird ; die Bedingungen können jedoch durch Ansammlung von Arbeitsaufträgen oder durch Zentralisierung bestimmter Arbeitsvorgänge in einzelnen Werken verbessert werden, da hierdurch die Arbeit in mehreren Schichten ermöglicht wird.

Beim *Schmelzen von Eisen* in Kupolöfen ist die Ausnutzung der Brennstoffe die allgemein übliche; beim *Schmelzen von Nicht-Eisen-Metallen und Legierungen* hat der Übergang von Öfen mit koksbeheizten Tiegeln zu neuzeitlichen mit Öl beheizten Tiegelöfen und tiegellosen Öfen zu einer wesentlich besseren Ausnutzung der Brennstoffe geführt (Wirkungsgrade bis 20% im Dauerbetriebe).

Für *Schmiedezwecke,* auf die im wesentlichen die oben gemachten allgemeinen Bemerkungen ebenfalls zutreffen, können bei offenen Schmiedefeuern nur geringe Wirkungsgrade erzielt werden (bis 5%, in Ausnahmefällen etwas höher), während die Schmiedeöfen bei Verwendung fester Brennstoffe bei guter Belastung eine Ausnutzung bis 15% und höher, bei Verwendung von Öl und Gas bis 25% und höher gestatten.

Bei den anderen vorkommenden Verwendungszwecken tritt die Ausnutzung der Brennstoffe hinter den Gesichtspunkt der Güte des Erzeugnisses zurück; dies trifft vor allem bei der Behandlung hochwertiger Stähle zu, bei der ein bestimmter Temperaturablauf und bestimmte Temperaturgrenzen eingehalten werden müssen, sei es, dass die Wärme unmittelbar oder durch Vermittlung von

Bädern (Blei- oder Salzbäder) auf die Stähle wirkt. Für diese Zwecke kommt die Verwendung von Gas oder elektrischem Strom, aber auch von Öl in Frage. Die Ausnutzung der zugeführten Wärme wird hierbei meistens dadurch verbessert, dass sie nach ihrer Wirkung auf die hoch zu erhitzenden Kammern zur Heizung von Vorwärm-Kammern dient, in denen die hochwertigen Stoffe entsprechend den Behandlungsvorschriften allmählich auf die geforderte Höchsttemperatur gebracht werden.

Überwachung des Brennstoffverbrauches

Prämienverfahren bei Lokomotiven. Für jeden Dienstplan und, falls Lokomotiven mehrerer Gattungen in einen Dienstplan eingereiht sind, für jede Gattung besonders, wird im Voraus für jeden Monat ein Richtsatz für den Brennstoffverbrauch, bezogen auf das Bruttotkm, ermittelt und dem Lokomotivpersonal vorläufig bekannt gegeben. Für Lokomotiven, die nicht in Dienstpläne eingereiht sind, gelten die Sätze der Dienstplanlokomotiven gleicher Gattung, die gleichwertigen Dienst verrichten. Ausserdem wird ein für allemal für jede Lokomotivgattung das Eigengewicht festgesetzt, das bei Berechnung der tonnenkilometrischen Leistung dem Zuggewicht zuzuschlagen ist; auch wird die Zugbelastung bestimmt, die bei der Umrechnung von Stundenleistungen in tkm einzusetzen ist.

Die Rechnungsunterlagen werden teils vom Zugführer und teils vom Lokomotivführer auf einem Ermittlungszettel beigebracht und von diesem auf eine Lochkarte übertragen, die zugleich der Errechnung seiner Aufwandsentschädigung dient. Die weitere Behandlung der Lochkarte, die zunächst noch einer Prüfung im Bahnbetriebswerk unterzogen wird, ist Sache der Lochkartenstelle bei der Reichsbahndirektion. Diese fertigt monatlich eine Aufstellung, auf Grund deren das Bahnbetriebswerk die Prämienanteile ausrechnet und zahlt.

Für jede ersparte t Kohle, deren Wert zu 28,—RM berechnet wird, werden dem Führer und Heizer je 20% dieses Betrages, d. s. 5,60 RM vergütet mit der Einschränkung, dass auf einen Kopf monatlich nicht mehr als 50,—RM gezahlt werden dürfen.

Ein Richtsatz wird ohne weiteres zum Darfverbrauchsatz, wenn er nicht mehr als 5% über oder unter dem Durchschnitts-Istverbrauch desjenigen Dienstplanes oder derjenigen Lokomotivgattung im Dienstplan liegt, für die er im Voraus angesetzt ist. Weicht er mehr als 5% von dem Durchschnitts-Istverbrauch ab, so ist der den Durchschnitts-Istverbrauch um 5% über- oder unterschreitende

Wert zum Darfverbrauchssatz zu machen. Diesen Spielraum in der endgültigen Festsetzung des Darfverbrauches hat man eingeführt, um den Umständen einigermassen gerecht werden zu können, die man im Voraus nicht kennen und daher bei der vorherigen Schätzung des Darfverbrauches nicht treffen kann.

Prämienverfahren bei ortsfesten Anlagen. Bei ortsfesten Kesselanlagen kann neben einer gewissenhaften Betriebsführung dadurch eine grössere Wirtschaftlichkeit erzielt werden, dass das Kesselbedienungspersonal durch Gewährung einer Prämie an einem sparsamen Brennstoffverbrauch interessiert wird. Als Grundlage für die Prämienberechnung können nur solche Faktoren in Frage kommen, die von den Heizern nicht beeinflusst und doch mit genügender Genauigkeit ermittelt werden können. Aus diesem Grunde müssen Dampf- und Wassermengen von vornherein ausscheiden. Ein gutes Bild für die Güte der Heizarbeit gibt hingegen die Messung der Kesselverluste, die ausserdem nicht durch das Kesselbedienungspersonal zu seinen Gunsten gefälscht werden kann. Die Herd- und Strahlungsverluste können hierbei unberücksichtigt bleiben, da sie in der Regel wenig schwanken und leicht vom Aufsichtsbeamten zu überwachen sind Sofern diese Verluste durch das Verschulden der Heizer dennoch unzulässig hoch werden sollten, könnte dies bei der Bemessung der Prämie berücksichtigt werden. Fur die Festlegung einer Prämie ist also lediglich die Messung der prozentualen Wärmemengen, die mit den Rauchgasen durch den Schornstein abziehen, erforderlich Diese sogenannten Schornsteinverluste setzen sich zusammen aus der fühlbaren oder freien Wärme und, sobald die Abgase nur unvollkommen verbrannt sind, aus der gebundenen Wärme.

Da Kesselanlagen in Bezug auf Art, Vollkommenheit, Betriebsweise und Art der Feuerbeschickung sehr verschieden sind, und auch die Zusammensetzung der Brennstoffe berücksichtigt werden muss, kann ein gerechtes Prämiensystem nicht nur auf den absoluten Wärmeverlusten aufgebaut werden. Es ist daher unerlässlich, dass vor der Einführung des Verfahrens durch planmässige Beobachtung und Messung, die zweckmässig über einen längeren Zeitraum ausgedehnt werden, die für die betreffende Anlage als angemessen zu betrachtenden Werte als Prämiengrenze festgestellt werden.

Die berechneten Kesselverluste dienen als Mass für die zu gewährende Prämie. Bei der Bemessung der Prämie ist zu berücksichtigen, dass in den Zonen der an sich schon kleinen Verluste weitere Ersparnisse ungleich schwieriger zu erzielen sind und daher höher

bewertet werden müssen, als in den Zonen der verhältnismässig grossen Verluste. Dieser Anforderung genügt die vom Verein für Feuerungsbetrieb und Rauchbekämpfung in Hamburg aufgestellte Kurvenschar, von der je nach Güte und Zustand der Anlage die Gruppen A bis E angewendet werden (vergl. Anlage 8).

Das auf dieser Grundlage aufgebaute Prämienverfahren ist bei einem grossen Teil der ortsfesten Kesselanlagen der Deutschen Reichsbahn-Gessellchaft mit gutem Erfolg eingeführt worden, so dass neben der an die Heizer zur Auszahlung gelangenden Prämie für die Verwaltung eine bedeutende Ersparnis verbleibt. Die Eigenart der Betriebe dieser Anlagen bringt es mit sich, dass wegen der schwankenden Belastung während eines Jahres mit nur einer Prämienkurve nicht immer auszukommen ist. Da die Belastungsschwankungen zur. Hauptsache durch den Heizbetrieb in den Wintermonaten hervorgerufen werden, hat es sich als zweckmässig erwiesen, für diese beiden Betriebsabschnitte je eine besondere Kurve zu wählen.

Brennstoffbuchführung und Brennstoffstatistik. Buchführung und Statistik sind für grosse Unternehmungen, bei denen Brennstoffe verschiedener Herkunft und Eigenart zahlreichen einzelnen Verbrauchsstellen zufliessen, als Mittel zur Überwachung des Brennstoffverbrauches und der Wirtschaftlichkeit hierbei unerlässlich. Die zunehmende Durchdringung des Unternehmens mit den wissenschaftlichen Methoden der Betriebswirtschaft führt auch zu einer Verfeinerung dieser Buchführung und Statistik. Sie sind nach 2 Gesichtspunkten zu behandeln und erfordern

(*a*) den Nachweis über den Verbleib der Mengen und Werte vom Einkauf bis zur Ausgabe an die Verbrauchsstellen, verfeinert durch die Angabe der Sorten und Verwendungszwecke,

(*b*) den Nachweis der Verwendung der wirtschaftlichsten Sorten für die einzelnen Zwecke und des mit ihnen für die verschiedenen Leistungen erzielten spezifischen Verbrauches.

(Zu a). Dieser Nachweis wird bei der Deutschen Reichsbahn-Gesellschaft durch die Stoffordnung geregelt und ist von grösster Bedeutung für die Beurteilung der Lagervorräte und für die Belastung des Betriebskapitals mit deren Wert sowie für die Einkaufspolitik, die auf die Konjunktur sowohl der allgemeinen Kohlenwirtschaft des Landes wie des Eisenbahnverkehrs Rücksicht nehmen muss.

(Zu b). Dieser Nachweis muss von den Verbrauchsstellen selbst geführt werden an Hand von Aufschreibungen, die die verwendete Menge und Sorte und den Verwendungszweck enthalten und jederzeit eine Nachprüfung ermöglichen (siehe Anlage 9).

Auch der spezifische Verbrauch kann nur durch die Aufschreibungen der Verbrauchsstellen ermittelt werden. Bei den Lokomotiven geschicht dies, indem die verbrauchte und ihnen angelastete Menge auf verschiedene Masstäbe, die sich noch in der Entwicklung befinden, bezogen wird. Bei den ortsfesten Anlagen liegen die Masstäbe durch die Menge des erzeugten Dampfes, der erzeugten Wärme, des geförderten Wassers, des durchgesetzten oder geschmolzenen Metalls fest. Die Verlustquellen können hier laufend genau erfasst werden (im Gegensatz zu dem Lokomotivbetrieb), wofür die Wärmebuchführung eingerichtet ist. An Hand dieser wird mit Hilfe von Temperaturmessungen und Rauchgasprüfungen sowie anderen kennzeichnenden Messungen die Betriebsführung und ihre Wirtschaftlichkeit, zu der auch die Auswahl der geeigneten Brennstoffe gehört, laufend überwacht.

SCHLUSSWORT

Die vorstehenden Ausführungen stellen einen Ausschnitt aus der Brennstoffwirtschaft der Deutschen Reichsbahn-Gesellschaft dar. Sie können bei der Kürze des für den einzelnen Bericht zur Verfügung stehenden Raumes nicht den Anspruch auf Vollständigkeit machen; sie geben aber einen Überblick über die Bestrebungen der Deutschen Reichsbahn-Gesellschaft, ihre Brennstoffwirtschaft einheitlich zu gestalten und zu überwachen.

VERZEICHNIS DER VERFASSER

1. Herausgeber.

Ernst Harprecht, Reichsbahndirektor und Mitglied der Hauptverwaltung der Deutschen Reichsbahn-Gesellschaft

2. Mitarbeiter.

Ernst Berg, Reichsbahnoberrat, München.
Eugen Keller, Reichsbahnoberrat, Karlsruhe
Dr.-Ing. Fritz Landsberg, Reichsbahnoberrat, Berlin.
Friedrich Modrze, Direktor bei der Reichsbahn, Breslau.
Leopold Niederstrasser, Reichsbahnrat, Oels
Professor Hans Nordmann, Reichsbahnoberrat, Berlin.
Leopold Sussmann, Reichsbahnoberrat, Altona.
Karl Vogt, Reichsbahnoberrat, Breslau.
Dr. phil. Hans Wefelscheid, Chemiker, Berlin.
August Zahn, Reichsbahnrat, Kassel.

RÉSUMÉ

The Federal Railway Company is one of the greatest consumers of fuel in Germany.

The yearly requirements amount to 14.4 million tons, of which 12·9 million tons or about 90 per cent. are used by locomotives, whilst the remaining 10 per cent. are consumed in stationary boilers. The methods of supervision and organisation in respect of this large quantity of fuel, in the form of laboratory testing and taking over supplies, as well as for the general control of

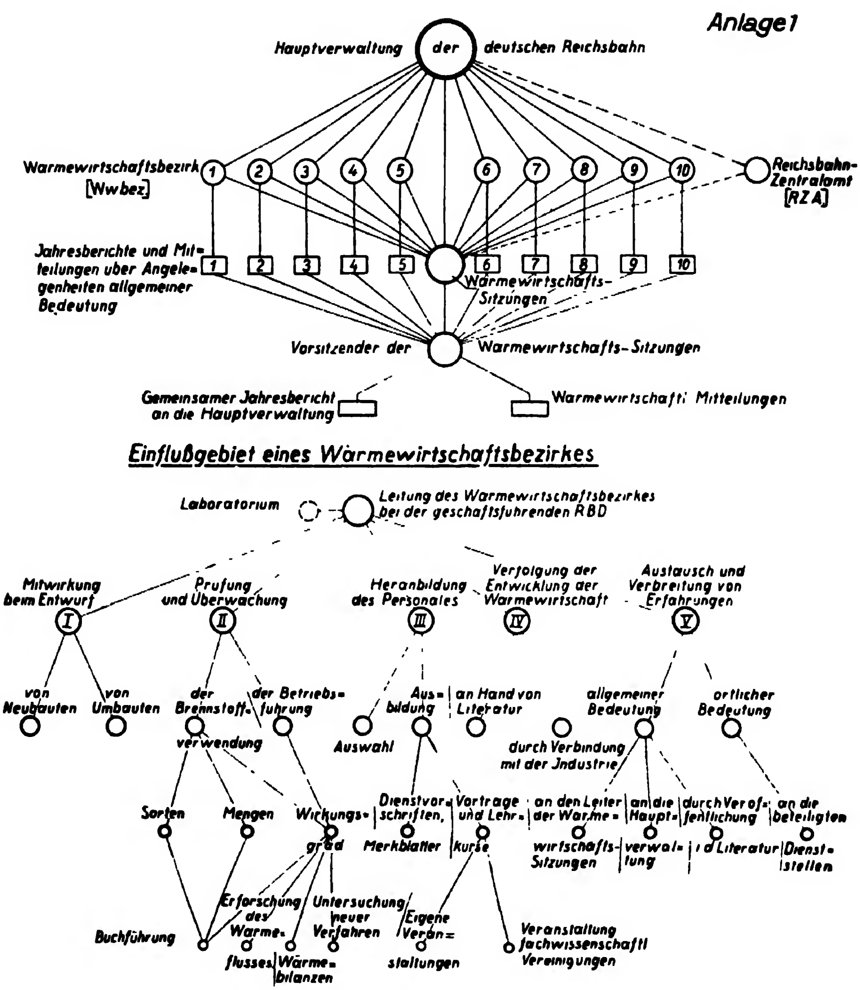
consumption, differ from the systems adopted in industrial undertakings on account of the wide distribution of the numerous points of consumption over the whole network of the German Federal Railway Company, with the consequent difficulties of individual supervision.

The three main sections are dealt with as follows:—

1. Quality test, taking over, storage and distribution.
2. Utilisation of fuels.
3. Control of fuel consumption.

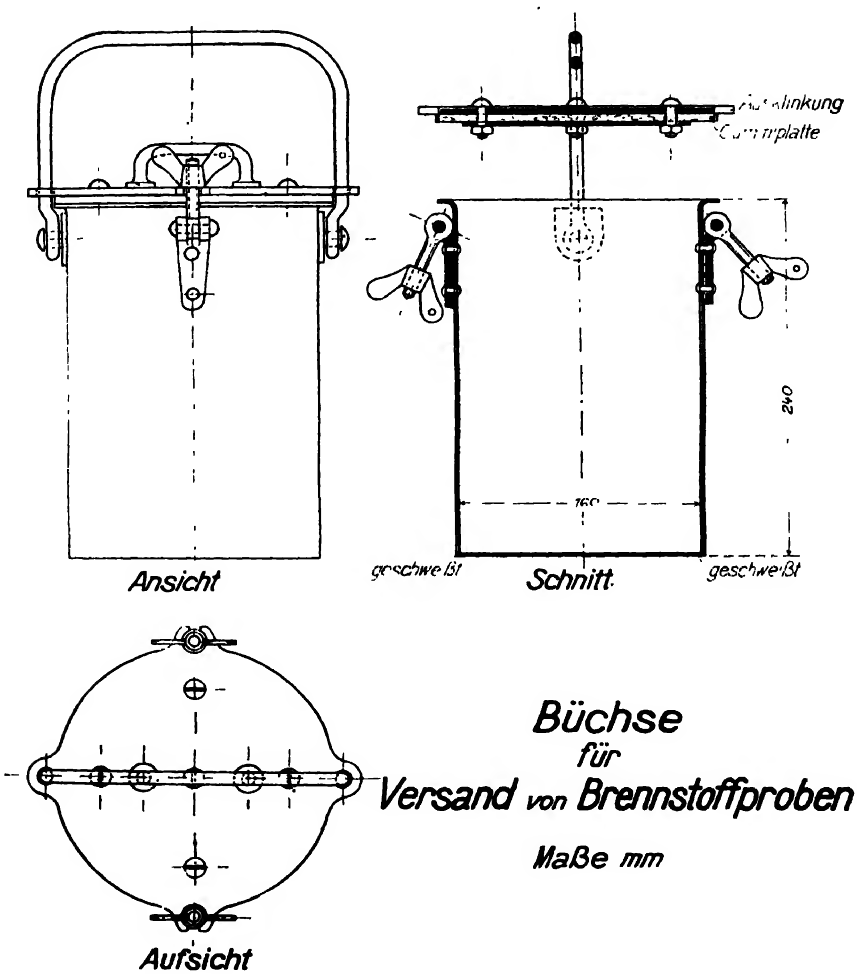
The requirements in various fuels, their testing both in the laboratory and otherwise, particularly by trial runs on given fuel, are discussed at length.

In the second part on the utilisation of fuels, the purposes for which they are employed by the Federal Railway Company, the most appropriate selection and their economical consumption are indicated. The third section is devoted to the control of fuel consumption by means of accounts and statistics and by the premium system for locomotive and furnace firemen.



Organisationsschema.

Anlage 2


240
geschweißt
Ansicht
Schnitt
Aufsicht
Büchse
für
Versand von Brennstoffproben
Maße mm

Begleitzettel für Brennstoffproben. **(*Vorseite*)** **Anlage 3**
Dienststelle:

***Datum*...............................**

T E L E G R A M M B R I E F .

U.g.R.

an das Brennstofflaboratorium.

im RAW T e m p e l h o f

Wir senden in Probebuchse No................*am* ..../.........192...
Brennstoffart ....
Brennstoffsorte ....
Grube, Zeche ....No ....
Schacht ....
Lieferer ....
Absendeort ....*Absendetag* 192
Wagen. .... No .... *Eingangstag* 192
Gewicht lt Frachtbrief ....*kg*
Anlass zur Untersuchung laufend, Beanstandung, Versuch, RBD Vfg. usw
....
....
....
Angabe der Entnahmestelle, falls die Probe nicht vom Wagen entnommen :
Kahn, Tender, Lager ....
Sonstige Bemerkungen ....
....
....
Die Probe ist vorschriftsmassig entommen worden

Dienststelle:

Unterschrift:

Bemerkung Vordruck sorgfältig ausfullen Nichtzutreffendes durchstreichen.
Eigne Anschrift auf d Ruckseite eintragen.

(***Ruckseite***) ***Urschriftlich***

....

durch.......................................

zurück.

Nr......... *Untersuchungsergebnis im Laboratorium Eingang am*
........./.........192.. ...

R O H K O H L E

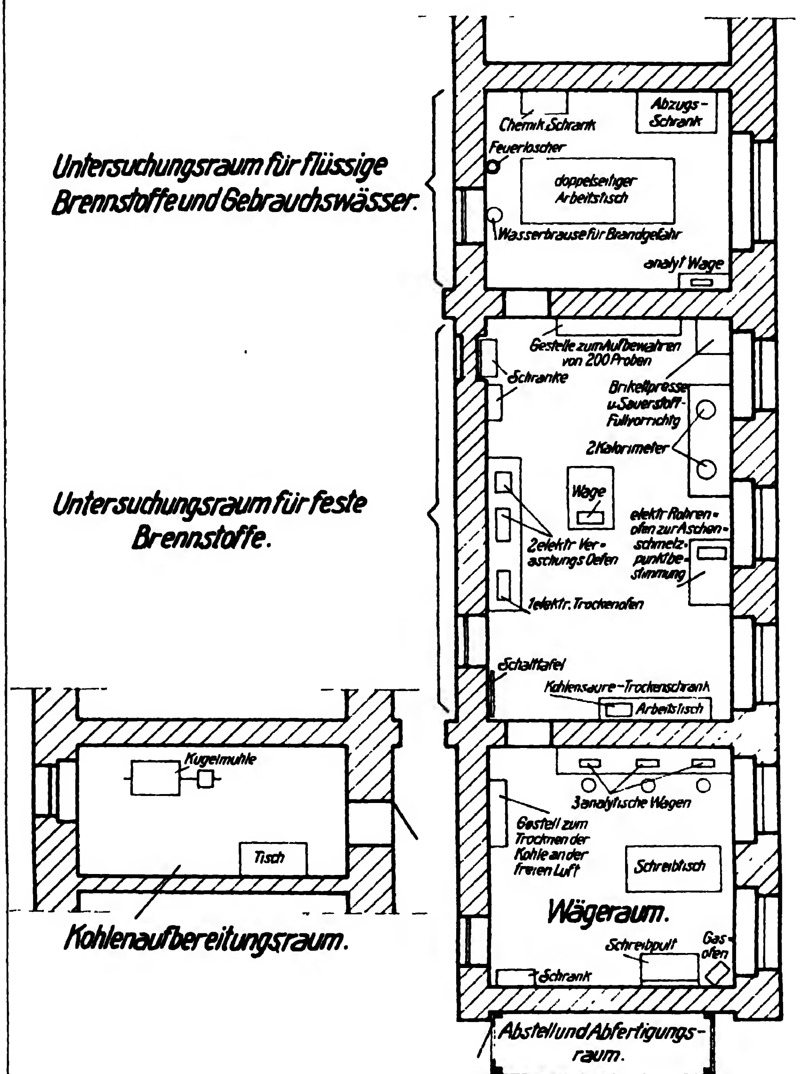
Gesamtwasser	...............%	*Asche Schmelzpunkt*............ C	
Asche	...............%	....	
Brennbares		....	
fester C	...............%	....	
fl. Teile	...............%	....	
Oberer Heizwert	..........*kcal/kg*	....	
Unterer Heizwert	..........*kcal/kg*	....	

R E I N K O H L E

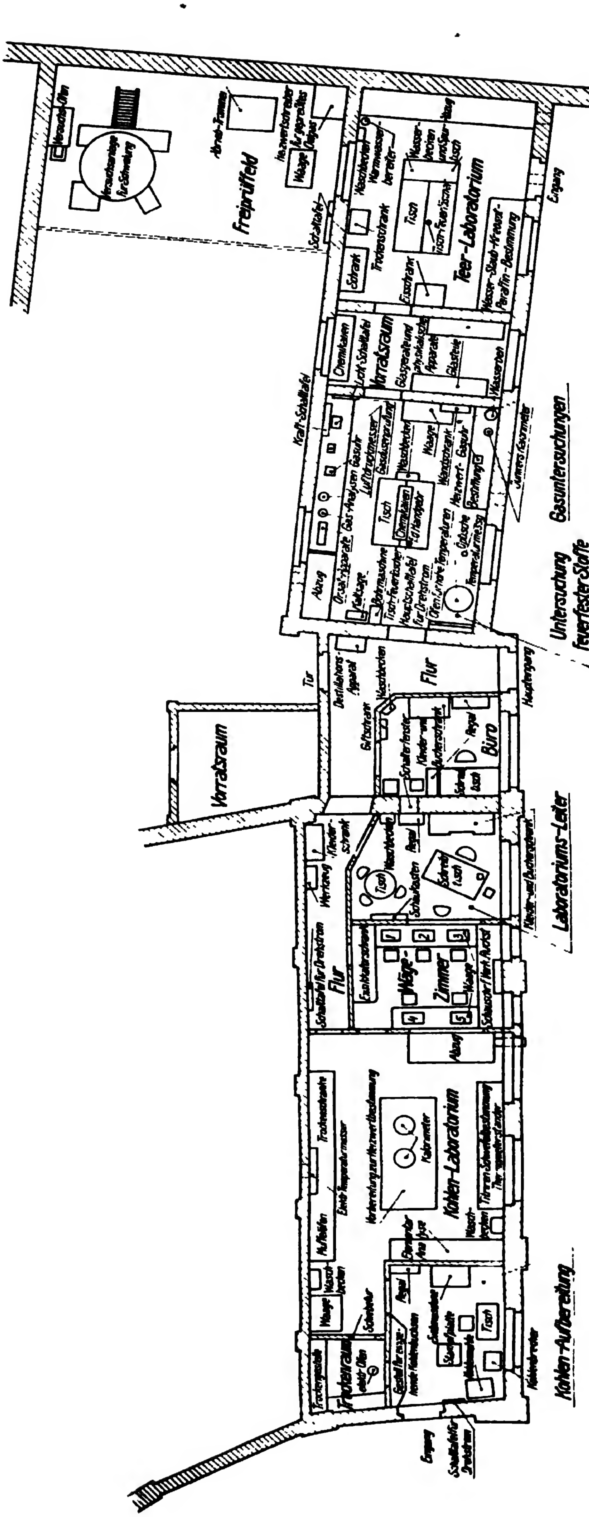
fl Teile ....% *Schwefel*...................%

Deutsche Reichsbahn-Gesellschaft
Wärmewirtschaftsbezirk

Anlage 4

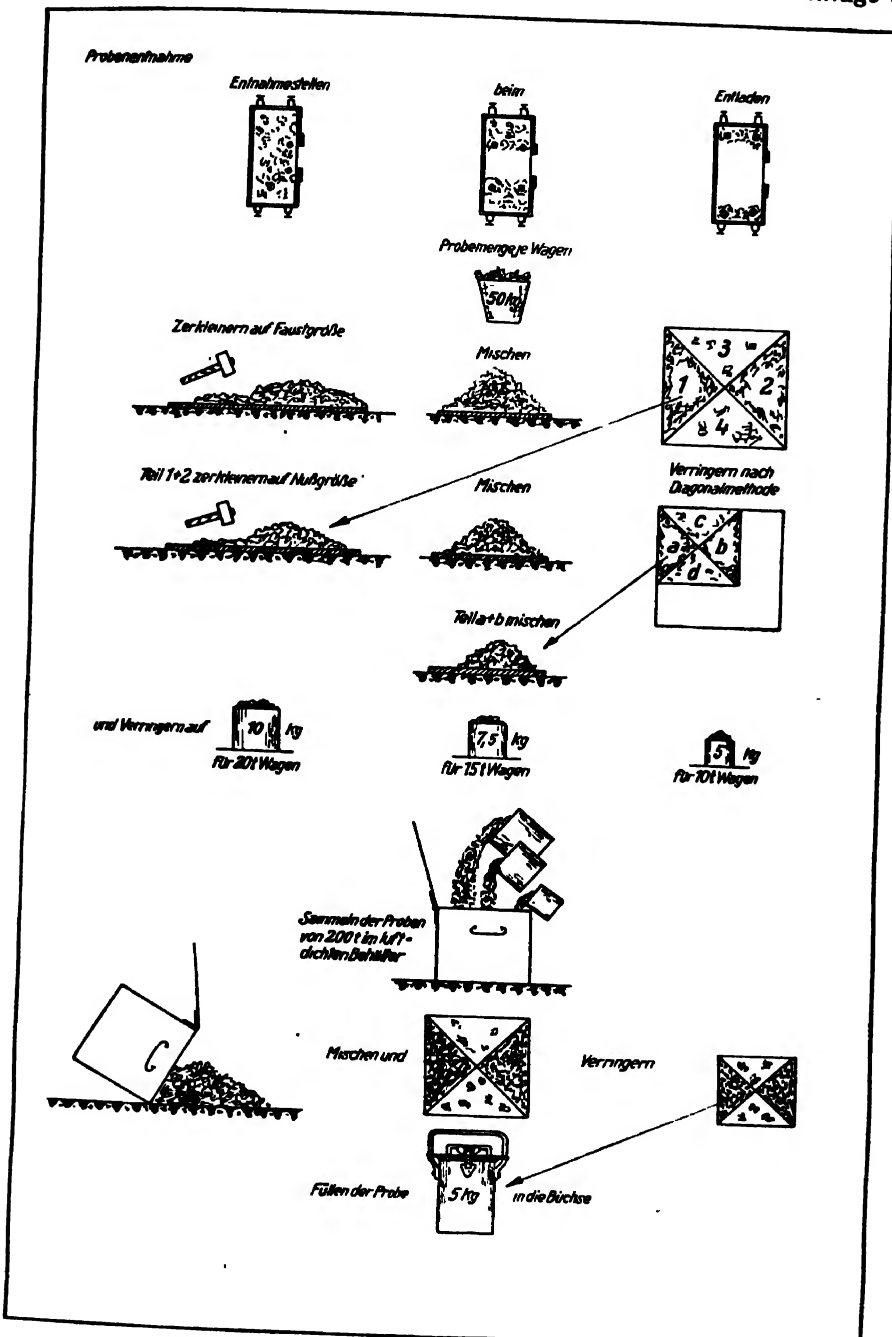


Brennstofflaboratorium
des Wärmewirtschaftsbezirks 3
Breslau



Brennstofflaboratorium des Wärmewirtschaftsbezirks Berlin

Anlage 6



Anleitung zur Entnahme von Brennstoffproben.

Anlage 7

Revier .... Art .... Sorte	Zeche und Schachtanlage .... Versuchsstrecke	RBD .... BW .... Ma .... lfd. Nr ....

Vom Versuchsleiter auszufüllen																Vom Bw auszufüllen				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Tag, Monat, Jahr	Zug-art und -nummer	Lok-gattung und -nummer	Witterung	Zug-gewicht	durch-fahrene Strecke	Lok-leistung Sp 5 × 6	Aufgewandte Fahrzeit: Gesamt Abfahrt Ankunft	Aufgewandte Fahrzeit: Unter Dampf	Flamme lang, mittel, kurz	Rauchbildung keine, unbedeutend, mäßig, stark	Brennstoff-verbrauch	Wasser-verbrauch	Menge der: Schlacke	Menge der: Asch-kasten- rückstände	Menge der: Rauch-kammer-rückstände	Kohlen-verbrauch für 1000 t km $\frac{Sp\ 12 \times 1000}{Sp\ 7}$	Asche-rück-stände $\frac{Sp\ 14+15+16 \times 100}{Sp\ 12}$	Verdamp-fungs-ziffer $\frac{Sp\ 13}{Sp\ 12}$	Heizflächen anstrengung $\frac{Sp\ 13}{m^2\ Heizfl \times Sp\ 9}$	Dampfentwicklung sehr reichlich, voll ausreichend, mäßig, nachlassend
				t	km	t km		h			kg	dm^3 (kg)	kg	kg	kg	kg	%		kg/m^2 h	

Beschaffenheit		Werturteil	
der Kohle	der Schlacke		Probe abgesandt am .... Aufgestellt und Richtigkeit bescheinigt Bw ...., den .... 192.... Der Dienstvorsteher

Vom Wärmewirtschaftsbezirk auszufüllen

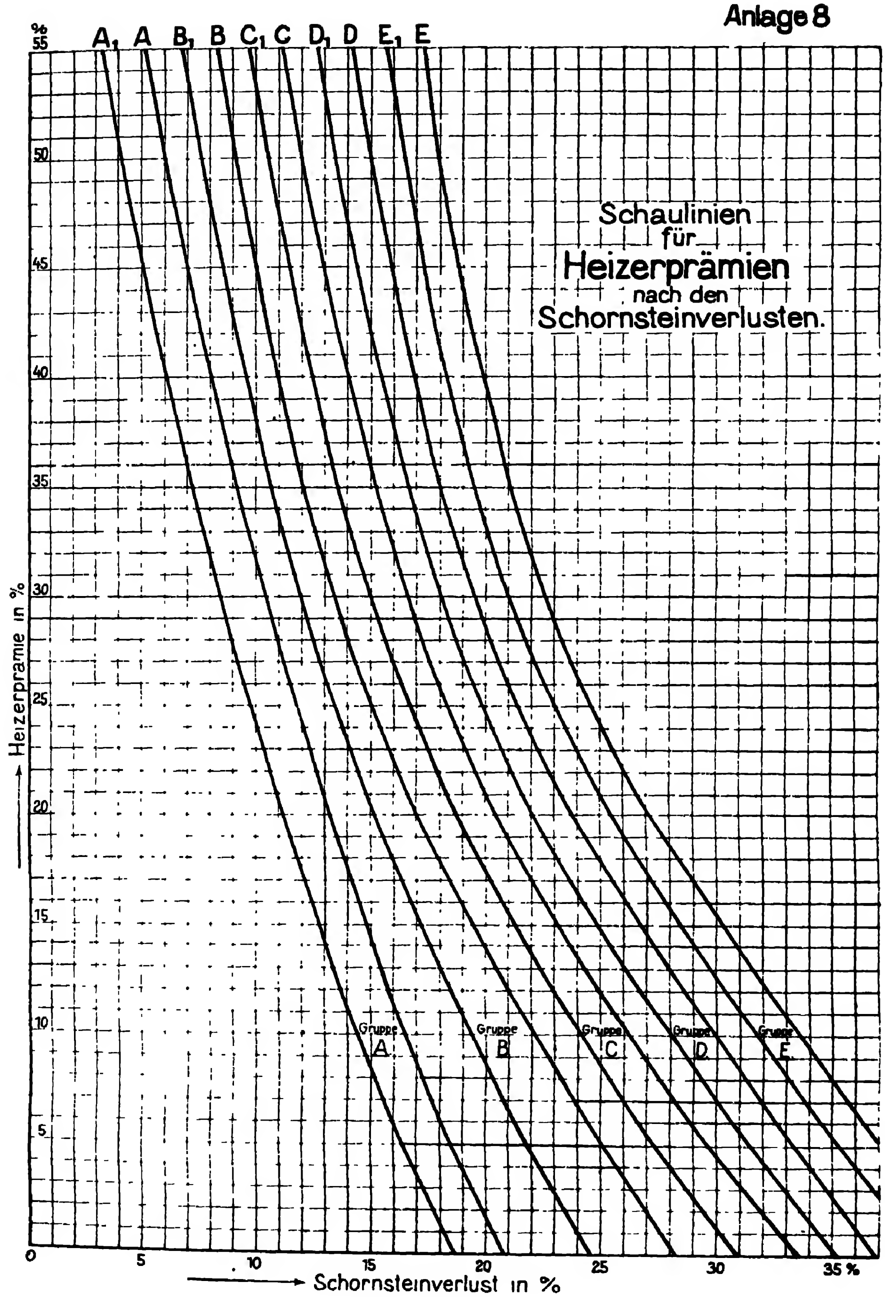
Die dazu gehörige Brennstoffanalyse Nr. .... ergab, auf Rohkohle bezogen, folgende Werte:

Wasser (insges.) .... % Unterer Heizwert .... kcal/kg
Asche .... % Aschenschmelzpunkt .... °C
Fester Kohlenstoff .... % Schwefel (auf Reink. bez.) .... %
Flüchtige Teile (auf Reinkohle bezogen) .... %

Rauchgasanalyse			Bemerkungen
der Fahrt am	CO_2 %	CO %	

Vordruck für Brennstoffversuchsfahrten.

Anlage 8


Schaulinien
für
Heizerprämien
nach den
Schornsteinverlusten.
A1 A B1 B C1 C D1 D E1 E
Gruppe A
Gruppe B
Gruppe C
Gruppe D
Gruppe E
Heizerprämie in %
Schornsteinverlust in %
%
55
50
45
40
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35 %

	101.01				101.02						101.03		101.04	101.05	101.06		101.07	101.08	101.09	101.10	101.11		101.12	101.13	101.14	101.15	101.17		101.18	699.11					Bemerkungen
Verbrauch im Berichtszeitraum	Stück-, Würfel-, Nußkohle	Förder u. bestm. Steinkohle			Nuß 2	Nuß 3	Nuß	Schmiedekohlen			Steinkohlenbriketts		Rohbraunkohle	Braunkohlenbrikett	Hüttenschmelzkoks		Gaskoks	Holzkohlen, weiche	Holzkohlen [illegible]	Brennholz	Nutzholz		Reisigwellen	Sägemehl u. Abfälle	Kohlenanzünder	Anheiztorf	Staub-Gruskohlen		Schwelkoks Grudekoks	Rauchkammerlösche					
	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	kg	kg	t	m	m³	hundert	Raum	Stück	t	t	t	t	t					
Bestand zu Beginn des Berichtszeitraums																																			
Zugang im Berichtszeitraum																																			
Gesamtmenge.																																			
Stoffnummer.																																			
1) **Kohle für alle Fahrzeuge, ausgenommen Betriebslokomotiven:** Werkdampflok., fahrb. Dampfkrane, Heizkesselwagen und ähnliche																																			
2) **Ortsfeste Dampfkessel:** Heiz- und Kraftwerke, Vorheiz-, Entseuchungsanlagen u. ähnliche																																			
3) **Niederdruckheizung und Warmwasserbereitung:**																																			
4) **Ofenheizung:** Öfen für Heiz-, Trocken-, Anheizzwecke und ähnliche																																			
5) **Fertigung in den Werkstätten:** Feldschmiede und Schweißherde, Schweiß-, Glüh-, Schmiede-, Gieß-, Schmelz-, Löt-, Härte-, Niet-, Abbrenn- und Trockenöfen bezw. Feuer																																			
6) **Gaserzeugung und Generatorenanlagen:**																																			
7) **Sonstige Verwendungszwecke:** In Spalte „Bemerkungen“ besonders zu kennzeichnen.																																			
Verbrauch zu lfd. Nr. 1 — 7																																			
Bestand zum Schlusse des Berichtszeitraums																																			

Brennstoffverwendungsnachweis.

Anlage 9

THE ECONOMIC UTILISATION OF FUEL IN THE PRODUCTION OF ELECTRICITY

INCORPORATED ASSOCIATION OF ELECTRIC POWER COMPANIES

R. P. SLOAN, C.B.E.

Paper No. J6

CONTENTS

Compared with the total quantity of fuel used in Great Britain for all purposes, the quantity used for the public supply of electricity is relatively small.

The total quantity of coal used in this country may be taken to be approximately 179 million tons, divided as follows:—

Purpose.	Million Tons.	Percentage Proportion of Total.
Household use	40·32	22·5
Gas production	16·66	9·3
Railways	13·51	7·6
General manufactures ...	100·85	56·3
Electricity works	7·75	4·3
	179·09 tons	100·0

Owing to improved methods it is likely that the quantity of coal used in the production of electricity will increase only slowly, if at all, during the next three or four years. That this is probable can be seen by comparing the amount of coal used per unit generated under present conditions with what should be attained in the course of a few years.

For the year ending March, 1927, the average amount of coal

consumed per unit generated was 2·43 lb. for all steam driven stations belonging to authorised undertakers in Great Britain.[1]

In large generating stations the coal consumed per unit generated will not exceed $1\frac{1}{2}$ lb.; consequently, as the proportion of electricity produced at such stations increases and the proportion obtained from small stations is reduced, a much greater output will be obtained from the same amount of coal. The difference in average coal consumption represented by the figures given above would result in an increase in output of approximately 60 per cent.

Another factor likely to retard the increase in the quantity of coal required by the electricity supply industry, will be a more complete use of such sources of waste energy as are available throughout the country.

Where surplus coke-oven gas is available, it may be economically possible to transmit this for the purpose of steam-raising on the site of a main power station, or, when the source of supply is too remote from the main power station site, it might be utilised in generating electricity on the site of the coke-ovens, and such electricity supplied into the general distribution system of a power company.

An example of the economy in the consumption of coal which may be looked for in this way is illustrated by the results at present being obtained by one of the power companies operating in this country. In this case the average coal consumption per total unit generated (by means of coal and waste energy) last year was 21 per cent. less than the average consumption per unit would have been, if generated by means of coal only.

In this connection, however, it must be remembered that steady efforts are being made in all directions to prevent waste in manufacture. Consequently, as time proceeds, the amount of waste heat available is, in fact, likely to decrease, and, having regard to the continued increase in the amount of electricity produced, it follows that the proportion of waste heat used for electricity production will steadily decrease, and it will be necessary to depend more and more on direct production. For this reason, and also because a decrease in the cost of fuel is hardly to be looked for, it follows that the closest attention to economical working will be increasingly necessary.

As electricity comes into still more common use, the quantity of fuel required for its production will, of course, increase more rapidly.

It is of considerable interest to arrive at figures showing the

[1]Report by Electricity Commissioners for the year ended March 31, 1927, on the Generation of Electricity in Great Britain.

relative importance of the cost of coal, as it affects the cost of electricity for various services.

It is all-important for large supplies, such as process work, where the use is continuous throughout the whole year, while, on the other hand, it is of relatively small importance for general supply, such as for lighting and for small power.

The following are typical figures setting out the proportion which the cost of coal bears to the other charges involved in providing a supply of electricity from a public supply system:

(1) LIGHTING OF SMALL HOUSES

No. of customers per 1,000 kW. of load at the power station:		10,000
These customers will consume:		1,000,000 units per annum.
The resulting revenue, at 7d. per unit will be:		£29,166 per annum.
The cost of providing the supply will be as follows:—		
Coal, at 20s. per ton:	£1,340	·32d. per unit.
Other payments, including interest, dividends and reserve:	£27,826	6·68d. ,, ,,
Total	£29,166	7·00d. ,, ,,

Percentage of coal cost to total costs: 4·6 *per cent.*

(2) AVERAGE HOUSE AND SHOP LIGHTING

No. of customers per 1,000 kW. of load at power station:		4,000
These customers will consume:		1,000,000 units per annum.
The resulting revenue, at 5d. per unit will be:		£20,833
The cost of providing the supply will be as follows:—		
Coal at 20s. per ton:	£1,340	·32d. per unit.
Other payments, including interest, dividends and reserve:	£19,493	4·68d. ,, ,,
Total	£20,833	5·00d. ,, ,,

Percentage of coal cost to total costs: 6·4 *per cent.*

(3) SUPPLY FOR POWER PURPOSES TO THE AVERAGE SMALL POWER CUSTOMER:

No. of customers per 1,000 kW. of load at power station:		200
These customers will consume:		2,000,000 units per annum.
The resulting revenue, at 1½d. per unit will be:		£12,500 per annum.
The cost of providing the supply will be as follows:—		
Coal, at 20s. per ton:	£2,230	·27d. per unit.
Other payments, including interest, dividends and reserve:	£10,270	1·23d. ,, ,,
Total	£12,500	1·50d. ,, ,,

Percentage of coal cost of total costs: 18 *per cent.*

(4) SUPPLY FOR POWER PURPOSES TO LARGE POWER CUSTOMERS:

No. of customers per 1,000 kW. of load at the power station:		3	
These customers will consume:		3,000,000 units per annum.	
The resulting revenue, at 0·8d. per unit will be:		£10,000 per annum.	
The cost of providing the supply will be as follows:—			
Coal, at 20s. per ton:	£2,400	·19d.	per unit.
Other payments, including interest, dividends and reserve:	7,600	·61d.	„ „
Total	£10,000	·80d.	„ „

Percentage of coal cost to total costs: 24 *per cent.*

(5) SUPPLY TO ELECTRO-CHEMICAL, OR SIMILAR WORKS:

No. of customers per 1,000 kW. of load at the power station:		1	
This customer will consume:		7,000,000 units per annum.	
The resulting revenue, at 0·4d. per unit will be:		£11,666 per annum.	
The cost of providing the supply will be as follows:—			
Coal, at 20s. per ton.	£5,000	·17d.	per unit.
Other payments, including interest, dividends and reserve:	£6,666	·23d.	„ „
Total	£11,666	·40d.	„ „

Percentage of coal cost to total costs: 43 *per cent.*

(6) SUPPLY TO VERY LARGE POWER CUSTOMERS: SITUATED NEAR POWER STATION

No. of customers per 10,000 kW. of load at the power station:		1	
This customer will consume:		40,000,000 units per annum.	
The resulting revenue, at 0·35d. per unit will be:		£58,333 per annum.	
The cost of providing the supply will be as follows:—			
Coal, at 20s. per ton:	£26,800	·16d.	per unit.
Other payments, including interest, dividends and reserve:	£31,533	·19d.	„ „
Total	£58,333	·35d.	„ „

Percentage of coal cost to total costs: 46 *per cent.*

It is clear from the above that, with the exception of the last two examples, the influence of the cost of fuel on the total cost of the supply of electricity is relatively small. It must not, however, be assumed that this ratio will continue, since as the cost of electricity supply is reduced there will be a more general and extensive use of electricity for domestic purposes, which will result in the cost of fuel representing as much as 20 per cent. per unit sold.

SUPPLY FOR HOUSEHOLD USE, ASSUMING THE GENERAL USE OF ELECTRICITY FOR LIGHTING, HEATING, COOKING, ETC.

No. of customers per 1,000 kW. of load at power station:		1,000	
These customers will consume:		2,500,000 units per annum.	
The resulting revenue, at 1¼d. per unit will be:		£13,021 per annum.	
The cost of providing the supply will be as follows:—			
Coal, at 20s. per ton:	£2,800		·27d. per unit.
Other payments, including interest, dividends and reserve:	£10,221		·98d. " "
Total	£13,021		1·25d. " "
Percentage of coal cost to total costs:	21·5 *per cent.*		

It is obvious that, to produce electricity at the lowest cost, a just proportion between capital and other charges and the cost of fuel must be attained so that the result will be a minimum. This consideration may, in the future, lead to a combination on the one hand of very large steam operated stations designed to work at a maximum economy coupled with secondary stations, possibly using oil fuel, designed and situated so as to involve the lowest capital cost, both in the construction of the power station itself and in the length of the mains to convey the electricity to the load centres.

Proceeding along the lines of present development, economy in fuel consumption at large steam stations must be sought in avoiding waste of heat at every vulnerable point. This end can be attained in well-known ways, such as by reducing the length and amount of steam pipes, by arranging them to admit of the simplest form of draining, and by designing boiler plant so that the combination of boiler, economiser and air heater is more compact, etc. In many designs at present the clear advantage to be gained by pre-heating the air is in a large measure lost by reason of the long ducts required to carry the hot air from the heater to the furnace, involving not only loss of heat but an expenditure of a considerable amount of power to move the necessary large volume of air.

One of the directions in which economy is being sought is in the use of steam at the highest pressure and temperature possible.

The economy to be gained by increasing the pressure is relatively small. The pressure, however, has an immediate bearing on the cost of the plant. Modern turbine plant can be produced at a low cost if a reasonable number of machines of the same type can be made from a given set of patterns, and in adopting higher pressures it is important to keep this fact in mind. It would be a considerable benefit if medium high pressure could be standardised at, say, 350 and 500 or 600 lb. per sq. in., and the employment of intermediate

figures avoided, as they merely result in increasing the cost of the plant.

The use of higher temperatures depends on the ability of the metallurgist to produce metals capable of working under the severe conditions that must arise when the temperature exceeds 700-800°F.

The relative advantages of firing with pulverised fuel, as compared with burning raw coal on automatic grates, is a subject too large and specialised to be dealt with in this paper. It may, however, be said in this connection that there are two broad matters to be considered—one, the difference in boiler efficiency possible with the two methods, and the other, the convenience and saving of labour of one method compared with the other. There are instances where cheap fuel is available which admits of its being burnt on the necessary large scale in pulverised form—and perhaps exclusively in that form—to far better advantage as compared with the raw form on ordinary stokers. Pulverised fuel plants have been put up solely to take advantage of such local conditions. The difficulty, however, is that in general the quantities of such cheap fuel are relatively limited and that, as soon as a free demand arises by reason of special plants constructed for its use having provided a market, the price of such cheap fuel tends to rise and approximate to that of other fuels. The advantage to be attained under these circumstances, therefore, is often shortlived.

Some collieries produce large quantities of fine coal, both of good and poor quality, which is often unsaleable. With improved methods of winning and treating the coal, the quantity of this fine coal may be reduced, but there will always be a certain quantity of this fuel for disposal. Where it is an economic proposition to transport this fuel, it may be utilised for the purpose of steam raising at a generating station situated at some suitable and convenient point for obtaining such supplies from a group of collieries.

Where the coal is of such poor quality that it will not bear transport charges, it may be consumed at the colliery itself and the electricity generated, over and above that required by the colliery, supplied to the distribution system of the power company.

In the processes carried out by large consumers of electrical energy, such as those referred to in examples Nos. 5 and 6 previously mentioned (p. 652), it frequently happens that steam heating forms an important part, and that back-pressure turbines may be used to advantage, and enable electricity to be produced at a much lower cost than by the adoption of any alternative method. Difficulties sometimes arise, as the requirements at the producing works do not

enable the full possible production of electricity to be absorbed locally. Such plants have, in these circumstances, been coupled up to a general distribution system, which is capable of absorbing any surplus energy over and above that required for the working of the particular process.

Before proceeding with the construction of a new process plant, the possibility of a general saving of fuel, which would be impossible otherwise to attain, should be explored. The power company supplying in the district is probably the best body for arranging such co-ordination.

Generally, economies in the use of fuel for the production of electricity cannot be considered apart from the question of the cost of securing such economies. With the extension of the inter-connecting trunk mains throughout the country, the economical working of the larger stations must steadily improve, as the increase of load factor at which they will be operated will make the economy in coal consumption of greater importance. The improvement in load factor must be secured mainly by the use of other stations to supply the peak load. It is desirable that these stations should use fuel as economically as possible but, on the other hand, since the total amount of fuel is a trifling proportion of the whole cost, the main consideration in their design will be to keep down the capital expenditure rather than to obtain the maximum efficiency in fuel economy.

Improvements in design of the main power stations, therefore, combined with the careful co-ordination of fuel-using plants in any manufacturing district and using the electric system as a link to make such co-ordination possible, are the directions in which the greatest success in fuel economy is likely to be found.

Another direction in which economies in the use of fuel may be looked for in the future lies in the treatment of coal in order to obtain the by-products, and the utilisation of the resultant semi-coke for the purpose of steam raising.

In considering the possibility of using coal distillation in conjunction with electricity generation, considerations may arise over and above the question of economy, such as the desirability of producing oil and other products to meet an increased demand.

Under present conditions, it is not likely that any large direct economies would result, but conditions may change, and consequently, the careful study and extensive experiments that are being made in this direction may be of the greatest use in the future.

It must, however, be pointed out that any distillation process involves a waste of the fuel treated to an amount necessary to effect the distillation.

There remain for sale, after distillation, coke, gas, ammonia and tar, and from the latter can be produced oil, motor spirit, the raw material for dye manufacture, and other products.

The commercial success of the process will depend on finding the best market for the sale of these products, as the power station can buy only the coke and gas and pay for them at their heat value. Under present conditions and at present prices, no important commercial economies have so far been obtained. This is indicated by the figures set out hereafter (p. 657), which show the results achieved from the coal distillation plant at the Dunston Power Station of the Newcastle-upon-Tyne Electric Supply Co. Ltd.[2]

The shortage of petroleum and petroleum derivatives during the war period forcibly re-directed attention to the waste involved in burning raw coal. After the war this shortage was quickly remedied, and the market values of the products of distillation have fallen consistently and heavily during the last six or seven years, but nevertheless coal distillation as an immediately urgent problem has been kept alive by a variety of factors. Chief amongst these is the rapid growth in the demand for petroleum derivatives in general, and for motor spirit in particular.[3]

The mere existence of so important an unsolved problem has been a serious consideration, and the constantly repeated warning that the world's known store of petroleum is rapidly being depleted has also acted as a definite incentive.

There would be certain important consequential advantages if coal distillation were widely adopted:

(1) To the extent to which semi-coke is used for steam raising, some 30 to 33 per cent. more coal must be mined to produce the semi-coke required for the generation of a given amount of electricity.

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[2]A description of this plant, together with a brief statement of some of the difficulties which had to be overcome by those associated with the Newcastle Company before the present measure of success was attained, are communicated later on in this paper.

[3]According to the Statistical Abstract for the United Kingdom 1911-1925 the motor spirit imported into the United Kingdom during the year 1920 (the first approximately normal post-war year), was 206,910,704 gallons. Seven years later, in 1927, it had increased to 538,306,509 gallons. (Gallon = volume of 10 lb. water.)

(2) Great Britain is largely dependent upon foreign supplies for the more important products of coal distillation, namely, motor spirit and paraffin.

As to the first, it is evident that in burning coal in its raw state full advantage is not taken of its potentialities. We are, therefore, not utilising in the most economical way what is possibly our most valuable raw material, and one which, from its nature and origin, is commonly and rightly referred to as a "wasting asset." As to the second, the importance of becoming self-supporting, in however small a measure, in the matter of fuel for necessary transport services, is self-evident.

It is, of course, well appreciated that the heat value of coal exists partly in its carbon constituent and partly in its volatile hydrocarbon constituent. It is not, however, so well appreciated that from 1 ton of coal—costing say 12s. and containing, say, 11,500 B.Th.U's per lb.—a number of derivatives can be obtained by distillation of the volatile constituent, the value of which is 10s. 6d., or 87 per cent. of the cash value of the raw coal.

COAL DISTILLATION PLANT AT THE DUNSTON POWER STATION OF THE NEWCASTLE-UPON-TYNE ELECTRIC SUPPLY CO. LTD.

Value of derivatives from 1 ton of coal (2,240 lb.).

	s.	d.
(*a*) *From distillation of volatile constituent.*		
1·0 gallon of motor spirit at 1s. 2d. per gallon	1	2·00
1·0 gallon of white spirit at 1s. 1d. per gallon	1	1·00
1·43 gallons of crude paraffin at 3¾d. per gallon		5·36
6·88 gallons of creosote at 8¼d. per gallon	4	8·76
5·0 gallons of pitch at 5·38d. per gallon	2	2·90
0·507 gallon of cresylic acid at 1s. 8d. per gallon ...		10·14
	10	6·16
(*b*) Semi-coke and gas having a calorific value equal to 0·76 tons of raw coal at 12s. per ton	9	1·44

(Gallon = volume of 10 lb. water.)
Average prices ruling in 1st quarter, 1928.

In other words, if the cash value of the raw coal is taken as 100, after distillation, two products are obtained, (*a*) derivatives with a cash value of 87, and (*b*) semi-coke with a cash value, on a thermal basis, of 76; or, taken together, a 63 per cent. increase in the cash value. The heat value of the coal which is not available for purposes of steam generation is only 2,760 B.Th.U's per 1 lb. of coal distilled, or no more than 24 per cent. of the heat value of the raw coal (*i.e.*, 12 per cent. heat value of oils and 12 per cent. heat consumed in process). Thus every ton of coal has what may be termed "high-value heat units" and "low-value heat units," and the aim of coal

distillation is to separate the two. The first effect of the application of heat to coal is to drive off the potentially valuable volatile matter. The residue is burnt, mainly into carbon dioxide, at a later stage of the combustion process.

The combination of coal distilling plant and steam raising plant involves submitting the coal to two processes. In the first, it requires heating to a carefully graduated temperature so as to drive off most of the volatile matter to form the fluid distillate. In the second the residue—the solid distillate—has to be delivered to the boiler furnace and burned therein, substantially as a smokeless fuel in the form of coke.

To evolve some practical and convenient means of applying these two separate processes was the first problem which those associated with the Newcastle-upon-Tyne Electric Supply Company set themselves to solve.

A number of distinct and rather intricate problems had to be solved before any degree of success could be attained. It was early determined to rule out all schemes involving the transfer of heat to the coal through some pipe or outer covering in favour of applying the heat directly to the coal, the object being to overcome the difficulty which arises from the fact that coal is a very poor conductor of heat. The first set of problems which arose was in connection with the choice of a distilling medium, and it was only after a long series of trials that an effective solution was eventually reached. Another set of difficulties arose in connection with the design and working of what may be termed the accessories of the plant, such as the coal feeding plant and pre-heaters, the internal arrangements in the retort itself, the coke extractors, stokers, furnaces and other details. The design and subsequent adjustment of these accessories occupied a long period of continuous attention. There is no space in the present paper for a detailed account of the frequent experiments and alterations which were made necessary by the absence of previous experience, and possibly little useful purpose would be served by such an account. The difficulties, and it is desired to emphasise that they were considerable, are here merely mentioned in passing.

Having decided the general character of the process, it was then necessary to determine the most convenient layout of the plant. This involved consideration of whether the coal distillation process should be carried out in a building independent of the power station, or whether it should form an integral part of the power station.

In the former arrangement the resultant coke would be delivered to the power station bunkers just as coal is delivered in normal

practice. It could then either be supplied direct to stokers or pulverised and fired in pulverised-fuel boilers. In the latter arrangement the distillation plant would form an integral part of the power station. This latter arrangement has in fact been adopted in the case of the plant installed at the Dunston Power Station of the Newcastle-upon-Tyne Electric Supply Co.

The plant is situated in the boiler house and the coke is taken direct from the retorts to the boiler furnace. Capital cost has thereby been reduced, and the arrangement has the further advantage that

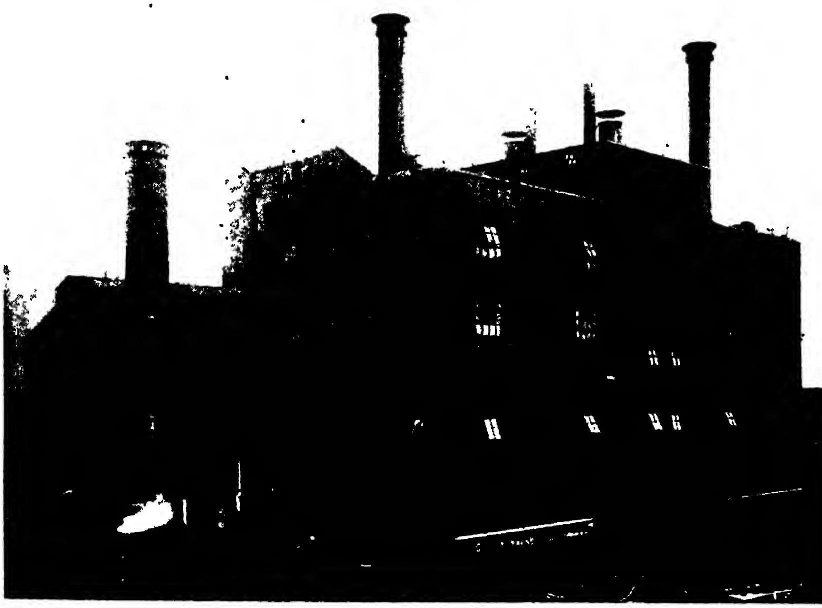

Fig. 1 Distillation Plant Boiler House.

the coke leaving the retorts is delivered continuously to the stoker hoppers, and part of its sensible heat is returned to the retorts and the balance to the boiler plant.

The distillation plant installed in the Dunston Power Station consists of four retorts and four boilers. The coal is screened, the fines being delivered through a pulveriser to one of the boilers which is arranged for pulverised fuel firing, whilst the screened coal is delivered to the retorts. The boiler plant operating in conjunction with the retorts consists of three Babcock & Wilcox coke-fired boilers, two of which are built together and have a combined

evaporative capacity of 18,000 lb. of steam per hour and one of 30,000 lb. of steam per hour. Each boiler forming the 18,000 lb. unit has its own retort which is capable of distilling 20 tons of coal per day. The 30,000 lb. boiler has two retorts, the combined capacity of which is 60 tons per day. The complete plant is, therefore, capable of distilling about 100 tons of coal per day and the resultant coke is available for firing the three boilers. The pulverised fuel boiler—or fourth boiler— has also an evaporative capacity of 30,000 lb. of steam per hour. This boiler is, of course, eminently suited for

Fig. 2. View of By-product Plant from roof of boiler house.

dealing with peak loads, and thus enables a steady load to be maintained on the coke-fired boilers, so that the throughput of the retorts is kept constant.

The condensing and gas washing plant for the recovery of crude tar and gas spirit is located outside the boiler house, as also is the spirit recovery and tar refining plant which is required for the production of the distillation products referred to on p. 9.

The general arrangement of the distilling plant, retorts and coke fired boilers is shown in the outline drawing.

The actual sequence of operations is as follows:—

Northumberland "rough small" coal is used, and on delivery to the station the fines are separated and delivered by conveying to the drying and pulverising plant, which serves the pulverised fuel boiler. The larger coal ($\frac{1}{4}$-in. upwards) is stored in two bunkers of 35 tons (2,240 lb.) capacity which feed the retorts. Before delivery to the retorts the coal is fed to pre-heaters, which are in the form of chain grate stokers housed in a brick setting, wherein the coal is heated to a predetermined temperature by waste flue gases. The object of the pre-heater is to prevent subsequent sticking of the

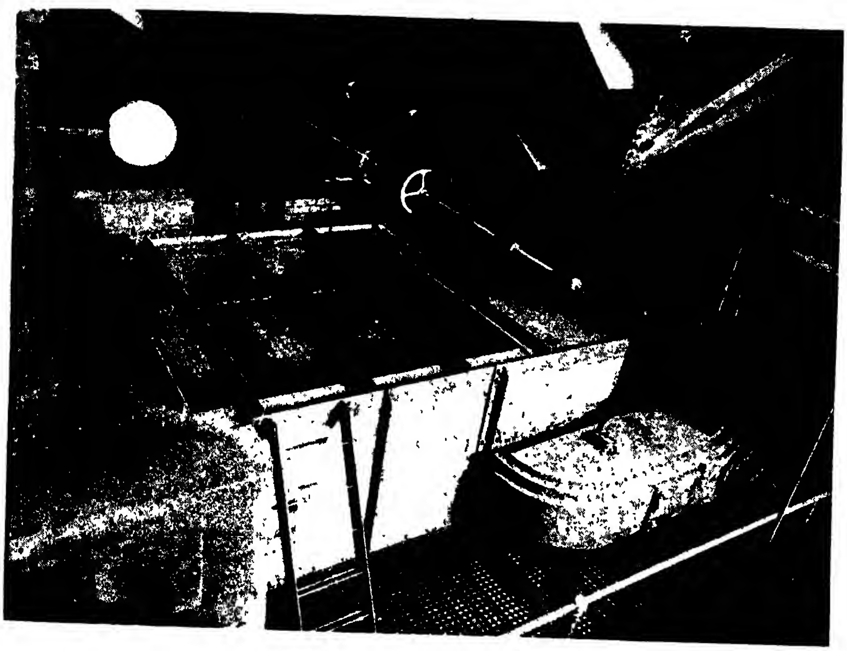

Fig. 4. Coal Preheaters on Retorts. In foreground, pre-heater cover removed to show chain grate.

charge in the retort, and to perform part of the heating of the coal by the use of waste heat from the boiler plant with consequent economy of heat.

The coal takes about 15 minutes to pass through the pre-heater, from which it is delivered continuously to the retort by means of a screw conveyor through a rotary valve, which also acts as a seal. In the retort the coal is spread and levelled, a constant level being automatically maintained.

The distilling medium consists of a mixture of steam and the

products of combustion from the burning of coke-oven gas[4] in a small combustion chamber arranged under each retort.

Low pressure steam at approximately atmospheric pressure, part of which is obtained by quenching the hot semi-coke in its passage to the stoker hoppers, is used for regulating the temperature and composition of the distilling gases which enter the retort through an annular space giving an even distribution of heat to the coal. The passage of the coal through the retort occupies about three hours, the extraction of the coke being effected by means of a series

Fig. 5. Retort Platform showing:
Left—Control instruments.
Right—Upper part of retort with coal feeding and spreading gear.

of hydraulically-operated toothed rollers which form the bottom of the retort. The hot coke is discharged continuously through coke breakers to a rotary scaling valve and thence by a screw conveyor to the stoker hopper.

[4]Coke-oven gas is used at Dunston as an ample supply can be readily obtained. Producer gas, water gas, or any other gaseous fuel can, however, be used, and if convenient pulverised fuel can be used. The Dunston Plant is equipped for the use of coke-oven gas, producer gas, and pulverised fuel, for heating the retorts.

Fig. 6 Gas Burner on retort combustion chambers.

Fig. 7. Hydraulic Operating Gear on coke extractors.

Meanwhile, the distilling gases and the volatile constituents of the coal are drawn off by a gas exhauster and passed through a filter which cleans the gas before it enters a water tube condenser in which the tar vapours are condensed, the crude tar being pumped direct to storage tanks. The gas is then washed with oil produced in the process for recovery of crude spirit and is conveyed to burners at the back of the boiler. Its calorific value as fired under the boilers is about 80 B.Th.U's. per cu. ft.

Fig. 8. Bottom of Retorts with coke-fed chain-grate stokers

As the spirit recovery and refining plant are designed on standard lines, it is not proposed to refer to them in detail.

The total cost of operation and maintenance amounts approximately to 4s. 8d. per ton of coal distilled. This figure is not an estimate, but the outcome of actual experience gained in the course of continuous operation for various long periods extending over the past three years.

Three shifts are worked during each twenty-four hours. The staff required per shift to operate the plant as it exists at present includes:

Two boiler firemen.
Two retort attendants.
One distillation plant attendant.
One ash man.
Two coal men } required on one shift per
One pitch man } twenty-four hours only.

A plant four times the capacity of the existing Dunston instal-

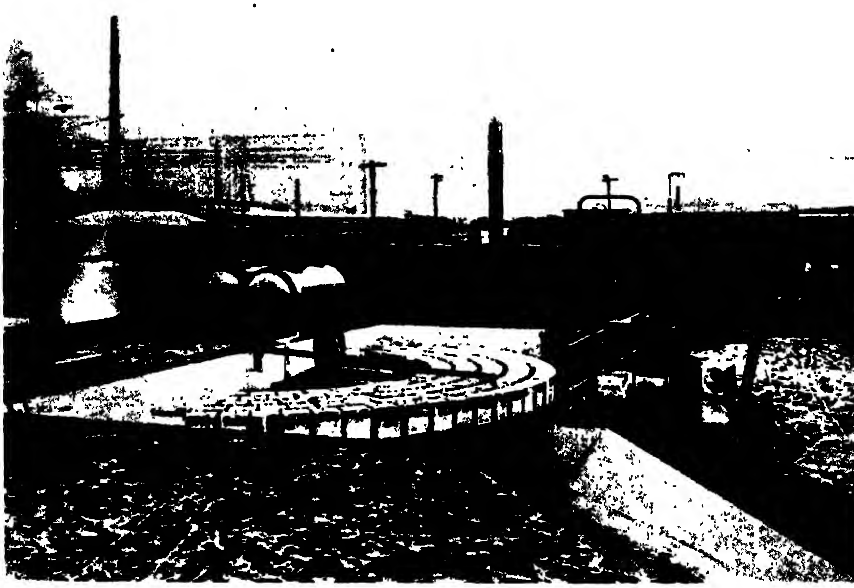

Fig. 9. Tar Stills with pitch block moulding plant.

lation could be operated with approximately 40 per cent. increase in labour cost and without any appreciable increase in the cost of supervision, thereby considerably reducing the operation cost per ton of coal distilled.

As regards the products of the process, the coke and surplus gas are fed direct to the boiler furnaces. The other products are refined and stored in tanks with the exception of the pitch, which is discharged into moulds of convenient size for disposal.

These products have found a ready market locally. The motor

spirit has been in use for some considerable time, and is giving satisfactory results under commercial conditions when used by a wide range of motor vehicles.

The Fuel Research Board have now for several years been conducting laboratory and fairly large scale experiments in the treatment of coal. It is important that large scale working, at least on a semi-commercial scale, should be carried on, since, in dealing with a large tonnage, difficulties arise, the effects of which on the commercial success of the process are often masked in small scale work.

To hasten progress, a speedy and frank publication of the results is of the greatest importance, and it is to be hoped that those at present engaged in this important work will pursue the course of early publication of any results that may be attained, whether successful or not.

ZUSAMMENFASSUNG

Während der letzten zehn Jahre hat eine grosse Steigerung der Erzeugung und des Verbrauchs an elektrischer Kraft stattgefunden. Es ist vorauszusehen, dass diese Steigerung noch mehrere Jahre zum mindesten anhalten wird. Es wird jedoch nicht erwartet, dass der Verbrauch an Brennstoff zur Krafterzeugung in demselben Masse zunehmen wird. Im Gegenteil, es ist sogar möglich, dass der Gesamtverbrauch an Brennstoff während der nächsten paar Jahre zurückgehen wird und zwar teils infolge der rationelleren Verwertung der Kohle in den Kraftwerken, teils infolge der besseren Verwendung des Stromes, wenn einmal das im "Electricity (Supply) Act, 1926" (Gesetz über die Versorgung mit elektrischer Energie, 1926) vorgesehene Hochspannungsnetz in Betrieb genommen sein wird, weiterhin infolge der ausgiebigeren Ausnützung der Abwärme z.B. vom Gas der Koksofen und ähnlicher Anlagen.

Um ein Bild von der Rückwirkung des Kohlenpreises auf den Strompreis zu geben, enthält der Bericht typische Zahlen, die das Verhältnis der Ausgaben für Kohle zu anderen, mit der Versorgung eines öffentlichen Netzes mit Strom verbundenen Ausgaben zeigen.

Es ist vorauszusehen, dass mit der erhöhten Verwendung der Elektrizität im Haushalt die Ausgaben fur Kohle im Verhältnis zu den Gesamterzeugungskosten für Hausstrom bedeutend steigen werden.

Es wird auch auf die bei Grosskraftwerken mit Dampfbetrieb mögliche Ersparnis an Brennstoff hingewiesen, die sich durch verbesserten Dampfkreislauf, Verfeuern von Staubbrennstoff usw. erzielen liesse, doch ist aus der Anwendung dieser Methoden eine nennenswerte Herabsetzung des Brennstoffverbrauchs nicht zu erwarten.

Man nimmt an, dass die Verbindung der Grosskraftwerke untereinander durch Hochspannungsleitungen, wie die im Regierungsbauprogramm vorgesehenen, weitere Ersparnisse bringen wird.

Die Möglichkeit, eine rationellere Brennstoffverwendung durch Destillation von Kohle zu erreichen, wird schon seit vielen Jahren erforscht. Es ist dies die in allen Gaswerken gebräuchliche Methode. Die Verbindung dieses Prinzipes mit der Erzeugung elektrischer Kraft wird ebenfalls seit vielen

Jahren erforscht, und Experimente aller Art in grossem Masstab ausgeführt. Der Bericht enthält Einzelheiten über kürzlich von den Kraftwerken von Newcastle-upon-Tyne in Dunston-upon-Tyne ausgeführte Versuche. Es wird auch kurz auf die Schwierigkeiten hingewiesen, die dabei zu überwinden waren, bevor man von einem Erfolg sprechen konnte. Schliesslich enthält der Bericht noch eine Beschreibung der Anlage.

UTILISATION OF LIQUID FUELS FOR THE GENERATION OF STEAM

TECHNICAL COMMITTEE, FUEL CONFERENCE, 1928

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ENGINEER-IN-CHIEF'S DEPARTMENT, ADMIRALTY

Paper No. J7

CONTENTS

Brief History of Development

It is proposed in this paper to deal with the question of the utilisation of liquid fuels for steam raising, mainly as applied to marine work, and it may, therefore, be of interest to trace briefly the history of the development of steam raising by oil fuel with particular reference to the Royal Navy, which has played no small part in the rapid advance made in recent years.

The earliest available records of practical experiments in oil fuel burning for naval purposes date back to 1864, when oil was burnt in pans or a series of cups placed one above the other in the furnace mouth.

These and similar methods failed on account of the limitation of the extent of the exposed surface of the oil, and it was realised that other methods would have to be adopted, if larger powers were to be obtained, and that the surface of the oil in contact with air would have to be considerably increased in order to obtain a more intimate mixture.

A system of steam spraying was introduced by Aydon and Selwyn in 1867, with results which proved satisfactory for the powers then in view, the system being developed under the personal direction of Admiral Selwyn, who was then Admiral Superintendent of Woolwich Dockyard.

In 1898 to 1899, when Sir John Fisher (as he then was) was Controller of the Navy, experimental work on oil burning was begun

in earnest. These experiments cannot be described in detail, but they led directly to the adoption of the pressure system which is now exclusively used for warships on service.

A considerable amount of experimental work was also carried out using steam or compressed air for atomising oil, but real progress in oil fuel burning for warship purposes was not made until pressure spraying or mechanical atomisation was introduced about 1902.

As an example of the disadvantages of the two former methods, it may be stated that the total steam required by the oil-fuel pump and by the oil-fuel heater for pressure spraying does not amount to more than 0·5 per cent. of the steam generated, as compared with not less than 5 per cent. required for steam or compressed air spraying, to say nothing of the loss of feed water in steam spraying and the addition of the heavy air compressor for air atomising.

Before any approach to finality was reached as to the form of the most suitable sprayer, a large amount of experimental work was carried out and the effect of temperature, pressure and viscosity on the nature and spread of the spray as it issued from the burners was studied in detail.

In 1903 a pressure sprayer of a new type was designed, in which a whirling motion was given to the oil; this sprayer, with slight modification, was adopted for general use and, with but very few alterations, has ever since continued to give efficient service.

During the experiments very valuable information was obtained on the question of the amount of combustion chamber space required for satisfactory burning of various liquid fuels and extensive trials were carried out on the combustion of oil fuel under varying conditions of air supply.

As a direct result the slotted steel air cone and, at a later date, the brick-lined combustion tube surrounding the sprayer were introduced. The air cone improves the mixing of the air and oil spray and partially vaporises the oil, thus allowing increased rates of burning without the dense smoke which had been previously such an objectionable feature.

Smoke windows were also fitted to the boiler uptakes to enable the men in the boiler room to detect any excessive smoke.

Following these experiments it was decided that all vessels building or completing, other than torpedo boats or destroyers, should be fitted to burn coal and oil in conjunction, the oil fuel being regarded as an auxiliary; also that all torpedo boats and destroyers due for delivery in 1906 should be fitted to burn oil fuel only. The results were generally satisfactory and consideration of reports received

from ships in commission indicated that the early difficulties, such as burning away of the steel cones, etc., could be overcome in future designs. The superiority of oil as fuel for naval purposes was clearly demonstrated.

Owing, however, to doubts which arose at the time as to whether sufficient oil fuel would be available to meet requirements in time of war, a reversion to coal burning was made in the destroyers ordered in 1908. The next group of destroyers and all other destroyers subsequently built were, however, arranged to burn oil fuel only.

It is interesting to note that tests were also made burning various types of oil, such as blast furnace and coal tar oils.

Results obtained during an investigation of the possible rate of evaporation for fire row tubes emphasised, incidentally, at the high rate of forcing possible with oil fuel, the importance of using clean water in order to avoid priming and deposits on the inside of heating surfaces, which would cause overheating.

The results of these experiments showed that it was practicable to burn as much as 1·2 lb. of oil per hour per square foot of heating surface.

Up to 1912, it had been usual to burn oil in conjunction with coal in the larger vessels, but at that date the ships of the *Queen Elizabeth* and *Arethusa* classes were designed to be fitted to burn oil fuel only.

By 1914 it was finally decided that adequate supplies of suitable oil could be arranged, and that in view of its many advantages, oil fuel only should be used generally for steam generation in the main boilers of H.M. ships. Boiler units generating steam sufficient for 10,000 S.H.P. and giving efficiencies as high as 84 per cent. and 72 per cent. at relative rates of burning of 0·2 lb. and 1·0 lb. of oil per hour per square foot of heating surface, have now become common practice.

Further developments, now in progress, involving higher steam pressures, necessitate the transmission of heat at higher temperatures with consequent higher flue-gas temperatures. The possibility of regaining some of this heat by the addition of an air pre-heating device where weight and space will allow, is also being considered.

The requirements of naval and commercial machinery run, to a certain extent, along parallel lines and, while the above indicates progress generally in naval practice, it may be taken also as an index to similar progress for commercial requirements.

Advantages of Liquid Fuel for Steam Raising

It is proposed at this stage to refer briefly to the technical advantages of fuel oils as compared with coal for steam raising, omitting for the time the purely economic aspect which must, of course, be affected by price considerations and availability of supplies. These may be summarised as follows:—

1. Oil can be stored in almost any part of the ship, thus giving considerable increase in stowage capacity and radius of action over vessels utilising solid fuels.

2. It has a higher calorific value. Further, when burning oil the gain in the heat effect is even greater than that due, theoretically, to the calorific value, as the better control and more stable conditions of air supply, due to the absence of necessity for opening furnace doors, etc., allows a closer approach to be made to the amount of air chemically required for combustion.

3. Demands for full power can be met in a very short time and steam can generally be more readily controlled.

An excellent example of this is the use of oil for steam generation in submarines, where boilers can be shut off so quickly that from full power on the surface the submarine can be submerged in less than five minutes and men can still remain in the boiler room without any degree of discomfort.

4. The absence of stoking or trimming, cleaning of fires and removal of ashes, assists materially in continuous high-speed steaming, and allows a considerable reduction in the personnel in the boiler rooms to be made.

5. The conditions in the boiler room from a hygienic point of view are also very much improved.

6. Losses due to unburnt fuel in the form of ash and clinker are considerably reduced.

7. On account of the increased efficiency of burning and higher calorific value of the oil, the weight of the boilers and the space required are less. In addition, owing to the absence of fire-grate limitations, boiler units of considerably increased output are possible.

8. Coaling ship is no longer necessary. This advantage is perhaps more forcibly illustrated from a naval point of view than any other, for, to take a concrete example, some twenty men can complete a large battle cruiser with, say, 2,000 tons of oil in four or five hours after the oiler is secured, whereas practically the whole ship's company of some 700 or 800 men is required for some twenty-four hours for coaling. Oiling ship is a comparatively simple operation;

the tank vessel comes alongside, hoses are shipped and the oil delivered at a rate depending on the capacity of the tank vessel's pumps.

9. Fuelling ships at sea can be more readily accomplished. This may be of special advantage to warships.

10. The watertightness of bulkheads can be better maintained, coal bunkers with their doors always being doubtful watertight compartments.

11. Oil can be readily transferred from one compartment to another to correct heel or trim, without the necessity of admitting water.

As an example of the advantages of oil burning, a modern torpedo boat destroyer, fitted with boiler units each developing 10,000 H.P., evaporating water at the rate of 18 lb. per hour per square foot of heating surface and burning 10 lb. of oil per hour per cubic foot of combustion space, has a total engine room complement of 28, with the ship developing 27,000 S.H.P. on a total weight of machinery, water, etc., of only 33 lb. per S.H.P.

It should be noted here that steam generation by powdered or pulverised fuel is claimed to be capable of development, so that some of the advantages stated above may be achieved by this method of steam raising. Whilst these claims are possible, it cannot, at present, be considered for naval services on account of its attendant heavy auxiliaries and extra personnel, together with the relatively low calorific value weight for weight and the consequent increased bunker capacity for a given endurance.

Suitability and Characteristics of Various Fuels

It is clearly desirable that a fuel oil for steam generation should possess high calorific value and be free from impurities. Further detailed general requirements for a fuel oil for steam raising may be stated briefly as follows:—

(*a*) The *Flash Point* must be sufficiently high to avoid danger from fire at ordinary temperatures and, for petroleum oils for naval purposes, it is required to be not less than 175°F. (Pensky-Marten) as compared with a minimum of 150°F. in commercial practice. With low viscosity oils such as distillates from shales, it should, however, be not less than 200°F.

On account of the danger of leakage into bilges, etc., and the stowage of oil under boilers, it is not generally considered desirable to reduce these figures.

(*b*) *Sulphur*. Not more than 0·75 per cent. is desirable, but in special cases this has been considerably exceeded, such oils being

utilised mixed with less sulphurous oils, so that the bulk percentage is reduced to not more than 1·5 per cent.

An early objection to sulphur rested on the possibility of corrosion of the pipes and systems, as well as furnace fittings, boiler tubes, and uptakes. It is, however, the free sulphur which is responsible for corrosion, and in general, this is not found to be serious within or near the limits mentioned above.

The oxidation products of sulphur are very objectionable and may affect the efficiency of boiler-room personnel and men working in exposed positions.

Sulphur compounds also tend to increase the emulsification tendency of an oil.

(*c*) *Water*. Not more than 0·5 per cent. is accepted in naval oils.

The presence of water is undesirable, as in addition to lowering the calorific value by loss of latent heat, it tends to cause spluttering which may eventually extinguish the burners.

(*d*) *Freedom from Acid*. The oil should be as free as possible from acid and never exceed 0·05 per cent. Oils having acidities over 1 per cent. have been used for blending purposes.

(*e*) *Viscosity*. The viscosity of the oil should not exceed 1,000 sec. at 32°F. (Redwood No.2) for ships not fitted with heaters in the tanks.

If heaters are fitted, oils of considerably greater viscosity can be used, but in general, oils having a viscosity not exceeding 1,000 sec. at 70°F. are about the limit for convenience.

The viscosity has an important bearing on the ease of handling and atomising.

The oil should not be too viscous to flow through pipes at ordinary temperatures, but when an oil has a high setting point, rendering it liable to solidify in the tanks or bunkers, it may be used by heating it sufficiently to allow pumping. Steam heating coils in the tanks and round the suction pipes are generally adopted for this purpose.

(*g*) *Impurities*. Oil should be free from earthy, carbonaceous or fibrous matter and other impurities likely to choke the burners; this applies particularly to asphaltic base oils, and it is sometimes specified that the oil, when supplied, should be capable of being pumped through a strainer having sixteen meshes to the inch.

It is desirable to know in each case the source from which the oil is obtained, the treatment to which it has been subjected and the ratio it bears to the original crude oil.

(*h*) *Mixing*. It is sometimes necessary to consider the characteristics of mixed oils, for, as it is not always possible to keep empty tanks in reserve, it is often necessary to use mixtures of oils obtained

from different sources. Certain straight oils are also blended in definite proportions with a view to minimising undesirable properties of one or more of the constituent oils, thereby allowing a more extended use of the oils possessing undesirable qualities.

As may be expected when two oils of different flash points are mixed, the greater the proportion of the low flash point oil the lower becomes the flash point of the mixture. It should be noted, however, that the lowering of the flash point of the mixture in some cases continues below that of the low flash point oil; thus two constituent oils which are separately suitable as regards flash point may, after mixing, have a flash point below the limit acceptable.

For steam raising, the residual product from the distillation of petroleum is now generally employed, but as the demand for the lighter fractions of petroleum such as petrol increases, it may be necessary to use still lower grade fuels for steam raising.

DATA CONCERNING FUEL OILS

		Texas	Burmah	Roumania	Mexican	Shale	Persian.	Trinidad	Fuel oil from coal (by vertical retort low-temperature carbonisation).	Blast furnace.	Good English coal.
Specific Gravity at 60°F		0·920	0·895	0·923	0·946	0·86	0·897	0·953	1·05	0·979	1·38
Composition Percentage	C	85·6	86·4	84·9	83·6	-	86·6	--	--	—	80
	H	11·03	12·1	13·96	10·9	-	12·3	--	--	-	5
	O	3·51	1·5	1·2	1·4	-	1·1	—	-		8
	Sulphur	0·6	0·2	—	3·5	0·35	1·4	1·0	0·67	—	—
	Water	0·4	0·1	-	0·5	0·05	0·1	0·2	0·1	·	--
Calorific value, B.Th.U.'s		19,200	19,300	18,500	18,300	19,150	19,200	18,770	16,500	16,080	14,112
Viscosity	No. 2 Redwood at 32°F	400	Set	9,585	3,000	10	Set	850	11,500	62	
	No 1 Redwood at 60°F.	500	100	2,000	4,500	65	450	1,800	4,500	72	..
	No 1 Redwood at 200°F.	38	30	58	13·3	28·8	35	--	-	Not used alone.	--
Flash Point		215°F	230°F	244°F	194°F	215°F	180°F	190°F	180°F	206°F.	
Particular Features		·	·	--	F.P. varies on different Mexican oils up to 240°F.	--	--	--	-	Contains naphthalene.	

NOTE.—Mexican oils cover a considerable range in flash points and viscosities. All oils have similar amounts of carbon and hydrogen in different combinations. The water present in each is variable and depends on the process employed to remove it.

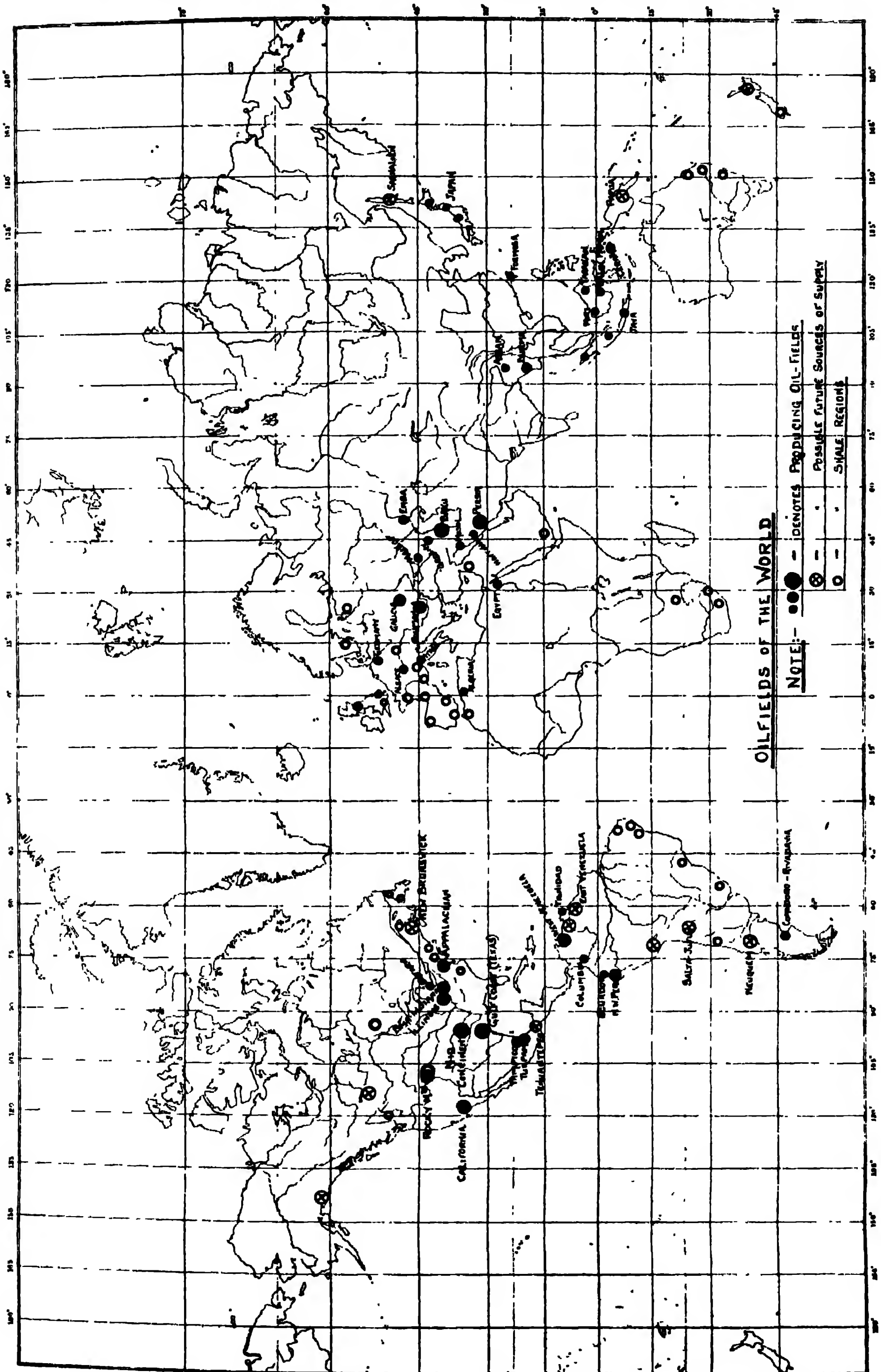
OILFIELDS OF THE WORLD
NOTE:- DENOTES PRODUCING OIL-FIELDS
" POSSIBLE FUTURE SOURCES OF SUPPLY
" SHALE REGIONS

Fig. 1.

The characteristics of some of the principal liquid fuels employed for the generation of steam are given in the accompanying table; exact knowledge as to their complicated structure is still limited, but a considerable amount of work is now being carried out on this subject

A general idea of the parts of the world where petroleum and shale have, hitherto, been discovered, can be obtained from the map (Fig. 1).

1. PETROLEUM. As can be seen from the table, the composition of petroleum residue oil varies slightly according to the field from which it is produced, but fortunately from the aspect of the steam raiser the variations are usually small, the carbon content generally, being about 85 per cent. and hydrogen about 11 per cent., whilst the calorific value varies between 18,000 and 19,500 B.Th.U.'s per lb.

Broadly, petroleums can be grouped into the paraffin and asphaltic base oils, but no definite division can be made.

To obtain the more valuable light fractions, the principal paraffin base oils, such as those from Pennsylvania and Persia, are generally subjected to a more complete distillation process than the asphaltic oils from California, Texas and Mexico, which were originally burnt as crude oils and which usually have a smaller proportion of the lighter fractions removed, so that a larger amount of residue is left for use as fuel oil. The latter residues usually requires more heating to reduce the viscosity for atomising.

It is understood that pulverised petroleum coke is already being economically used as a substitute for pulverised coal in America and it is stated to have the advantage of giving little, if any, of the troublesome ash found in many pulverised coals.

2. SHALE OILS. There are large deposits of oil-bearing shale from which oil, known as shale oil, can be removed by destructive distillation, specially constructed retorts being used.

These shales form a big reserve of fuel oil, as, for example, the surface shales in the United States of America, but at present the production of shale oil does not compare economically with that of petroleum.

On this account the shale industry has been subjected to periodic waves of depression and while it has been stated that in a limited number of years the shale mining industry in some countries will be on an even larger scale than coal mining, it seems probable in this country that, unless it is protected by a subsidy or other means, production is not likely to be developed to any very great extent unless shortage of petroleum renders it an economic proposition. This is a most unlikely contingency for many years to come

Shale oil is generally a good quality oil which can be easily atomised at ordinary temperatures and is light and mobile. The oil produced from some forms of shale, *e.g.*, Kimmeridge, contains large quantities of sulphur, the removal of which has not yet been successfully accomplished.

3. Coal Tar Oils. These are of considerable importance to the coal-bearing countries; their composition depends to a great extent on the character of the coal from which they are produced and also upon the method of production. Creosote oils (by-products of gas works and blast furnaces) mixed with petroleum, were for some years used for steam raising in the Navy, but owing to their use for other purposes, the price became prohibitive, so that for the present their use is in abeyance. Further, as long as petroleum oils could be obtained, it was perhaps natural that they would be preferred to oils which have lower calorific value and which could not be used alone owing to the fumes. Creosote oils have been supplied to the fleet, mixed in the proportion of one creosote to two of petroleum, the resulting mixture being fluid at all normal temperatures and having a viscosity not exceeding 1,000 sec. at 32°F.

Numerous efforts have been made to use tar oils containing pitch by mixing them with other oils, but this generally brings down deposits which are difficult to handle in installations primarily designed for the use of petroleum oils. If, however, these tar oils are subjected to further distillation for the removal of pitch, the distillates obtained are found to be miscible with petroleum. They contain, however, a certain amount of free carbon which is liable to give difficulty in burning, with the production of smoke and possible choking of filters, etc.

The production of oils by low temperature carbonisation of coal, offers definite attractions, apart from its economic advantage in countries where supplies of natural oil do not exist, in view of the more complete utilisation of the heat value of the coal obtained in this way and the elimination of smoke. For example, the odd 40 million tons of coal burnt annually in this country could be treated in such a way as to produce a smokeless domestic fuel and, besides many valuable by-products, some 10 to 14 gallons of fuel oil per ton of coal, which would provide a substitute for at least a portion of the petroleum oils now imported. This problem is, however, still far from complete solution on a commercial scale, and like the shale industry, would appear to require, in the earlier stages, some form of government subsidy or protection to render it

free from the fluctuations in prices of other fuel oils; the difficulties in disposing economically of the by-products on a large scale, and the relatively small amount of oil produced, render the problem a difficult one.

It may be mentioned in this connection that, if a market can be found for these by-products when produced on a large scale, the production of oil from coal would appear likely to compare favourably with the production of oil from shale, in view of the larger amount of waste contained in the by-products from the latter.

A method by which larger proportions of oil can be obtained from coal, the Bergius or hydrogenation process, has lately been developed in Germany and in this country. Statements have been made that it may be possible in the future to produce sufficient liquid fuel from coal by this method to avoid the necessity of importing oil. The economical development of this process, which requires a very expensive plant, is, however, largely bound up with the cheap production of hydrogen and must, to a large extent, be dependent on the latter.

4. Colloidal Fuel. Although not strictly within the subject matter, colloidal fuel should also be mentioned. This consists essentially of fine, powdered coal held in suspension in about its own weight of oil, and the mixture is stated to possess all the properties of liquid fuel. Even under ideal conditions there is, however, some doubt as to whether the solids remain suspended for more than a few months and, so far as is known to the author, the claims for a stable colloidal fuel have yet to be substantiated.

The advantages claimed for the development of colloidal fuel are that it would have a greater available calorific value for a given volume. This is of interest where available stowage space is all important and on account of the possibility of reducing our oil imports.

Burning Liquid Fuels

The development of fuel oil burning, as applied in the Navy, has already been briefly traced and before considering in detail the question of oil burning, Fig. 2, which indicates the course of the oil from the tank to the furnace for a typical naval installation, may prove of interest.

The first essential for the successful burning of liquid fuels for steam raising is to achieve a suitably intimate mixture of oil and air, *i.e.*, to produce the finest possible spray and spread it out in such a way that, with a suitably arranged air supply, each particle

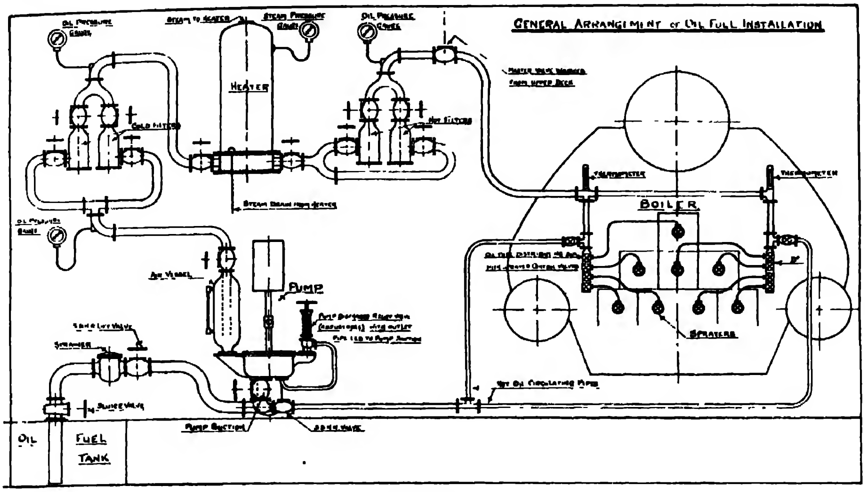

Fig. 2.

of oil can receive the amount of oxygen required for complete combustion before it leaves the combustion space.

Several methods of accomplishing this have been successfully applied. These can be divided broadly into those which use an atomising agent such as air or steam and those which eject the oil under pressure through suitably shaped orifices, currents of air being arranged so as to impinge on the resulting spray.

With the steam injector system it is a simple matter to get a smokeless flame and the steam injection burner gives remarkably good results, owing possibly to the chemical activity of the mixture of heated hydrocarbons and water vapour.

The weight of auxiliaries is also cut down, but the ensuing loss of feed water may amount to 10 per cent. of the total evaporation, which is clearly inadmissible for most marine services. Heat must also be expended in making up this loss of water by further evaporation of sea water.

These objections are, of course, so vital that they render the method quite useless for marine installation; steam injection is, therefore, restricted to very special services only.

A very high rate of combustion can be achieved with air injection and, while there are interesting possibilities in this form of spraying, the size and upkeep of the necessary air compressors at present prohibits the use of this system for marine purposes or for general use in steam raising.

With the pressure type of sprayer now generally adopted for naval purposes, oil which has been heated to a suitable temperature in

special oil heaters is sprayed in a fine mist from a small exit hole in the sprayer cap. In this type of sprayer the oil is led under pressure into a cylindrical chamber immediately behind the exit hole and a rotary motion given to the oil in the chamber by making the oil ducts to the chamber tangential to the circumference. The oil passes out of the exit hole, which is concentric with the whirling chamber, in a hollow cone of finely divided spray, with which it is easy to mix the air required for combustion.

The angle of the cone of spray is governed mainly by the whirling speed inside the cylindrical chamber, which can be modified by the number and size of the tangential holes and of the exit hole.

The output of the sprayer depends on the size of the exit hole, the pressure under which the oil is ejected and the area of the tangential holes, as well as on the viscosity and specific gravity of the oil. Providing the other variables are maintained constant, the output is proportional to the square root of the pressure for any given type of sprayer, noting, however, that the pressure must always be maintained sufficiently high to atomise the oil effectively, and that pressures between 50 and 175 lb. per square inch are usually employed.

It is found that the best spray is obtained when the temperature of the oil is such that the viscosity is about 40 sec. (Redwood No. 1), this being about the same as that of distilled water.

When using viscous Mexican and other crude oils or heavy distillates, the consideration of the degree of viscosity becomes a matter of considerable importance.

The viscosity and specific gravity of an oil vary with the temperature, which thus becomes an important factor in determining the output of any sprayer and makes it essential to know the correct temperature at which the viscosity shall be that desired.

The specific gravity appears to decrease by approximately 0·0004 for every 1°F. rise in temperature and this rule is sufficiently exact up to 200-250°F. for all practical purposes.

The relation between viscosity and temperature is far less simple and no general rule has been found which is applicable to all classes of oil fuels over the usual range of temperature.

Experimental work appears, however, to indicate that if plotted logarithmically, the logarithm of the viscosity varies directly as the logarithm of the temperature and that all oils have approximately the same viscosity at 450°F. While this law appears to be approximately true for the majority of oils up to 150°F., it cannot be applied in all cases.

The combined effect of viscosity and specific gravity is found to be such that an increase of the burning temperature is accompanied by a decrease in output, in other words the decreased specific gravity over-rides the increased volumetric output obtainable on account of the lowered viscosity.

From the point of view of efficient combustion, however, the higher the temperature at which the oil leaves the sprayer the better, up to and within about 5°F. above the flash point, because, as well as lowering the viscosity and thereby assisting the dispersion of the mist, the oil is nearer to ignition temperature and burns more quickly, *e.g.*, it has been found by experiment that a decrease in temperature of an oil (Texas) from 210°F. to 170°F., causes an increase in uptake temperature of 50°F.

Higher temperatures than those indicated above should not be used, as a sudden reduction in pressure might result in cracking and consequent carbonisation in heaters and pipes. This consideration would influence the selection of oils when a free choice exists, *e.g.*, with Texas oils the best viscosity for spraying is at about 210°F., the flash point being about 214°F., whereas with a Mexican oil the best viscosity is at about 300°F., but the flash point limits the burning temperature to about 190°F.

"U" tube heaters, with steam on the outside of the tubes, are generally used for heating the oil. About 17 sq. ft. of heating surface are usually allowed per 1,000 H.P. developed.

Air Supply

For economical and successful burning of the fuel it is essential that the air supply should be correct, not only in quantity but also in regard to the method of application, particularly as a particle of oil can pass from the sprayer and out of the funnel in under one and a half seconds.

The quantity of air required theoretically varies slightly for different types of fuels, depending on the chemical constituents of the oil, the proportion in which they are present, etc., but for practical purposes such variations are unimportant, and actually the quantity of air required for the complete combustion of 1 lb. of oil may be stated to be about 15 lb.

The presence of excess air or the reverse can be detected in a practical manner by observing the products of combustion either at the funnel top or by a mirror device in the uptakes. White smoke is formed when too much air is supplied, due to unburnt oil vapour leaving the funnel, and black smoke will be formed when too little

air is supplied, due to particles of unconsumed carbon. There is, however, between black and white smoke a considerable margin which allows a range of inefficient burning, which is avoided in practice by allowing a slight brown haze, care being exercised, however, that this is not due to extraneous causes such as dirty sprayers.

A more exact method of determining the efficiency of combustion, now almost universally adopted, is the chemical analysis of flue gases, carried out either by collecting samples of the funnel gas for analysis by the "Orsat" process, or more usually by semi-automatic devices such as those provided by various instrument makers. Instruments have also been devised for measuring the percentage of combustible gases going to waste, but it remains to be proved whether a satisfactory design of this instrument can be produced to meet sea-going requirements.

A further and perhaps more practical check on the efficiency of combustion at any given output is obtained from the funnel temperature

The fact that the percentage of CO_2 in flue gases is to some extent a reflection of the efficiency of combustion, is generally utilised in the methods mentioned above, *e.g.*, if too little air is supplied only sufficient oxygen will be present to burn a portion of the carbon to CO_2 and the remainder will be burnt to CO. The loss of heat due to burning 1 lb. of oil to CO instead of CO_2 represents a loss of 10,000 B.Th.U. and in a funnel gas even 1 per cent. of CO in the presence of 12 per cent. CO_2 means a loss of up to 8 per cent. of the total heat. Slight excess of air over that required theoretically is necessary in practice to avoid incomplete combustion and although the theoretical amount of CO_2 should be roughly 20 per cent. of the products of combustion, approximately 14 per cent. is present under normal working conditions.

Excess air, in itself a great loss as it directly cools the heating surfaces being heated to flue temperature, tends to slow up the speed of combustion and, as in the case of a cold oil supply, increases the temperature of the uptake, but to a more marked degree. In addition, it necessitates an unnecessary load on the fans and an increased steam consumption amounting to as much as 8 per cent.

Having discussed the means adopted for spraying the oil and the quantity of air required for combustion, we come to the consideration of the best means of obtaining a good mixture of the air with the oil, in the correct proportions and at the required position. This has only been achieved after prolonged experiment and while

many slight variations in method have been adopted the oil is generally sprayed into the boiler through a combustion tube and the air necessary for combustion admitted under pressure around the outside of the oil spray through inlets suitably arranged to give the required degree of turbulence.

There are, however, two distinct methods, one in which the oil is sprayed directly into the furnace as a distinct oil spray and the second, used in the Royal Navy, in which the oil is first sprayed into a hot tube and emerges at the furnace end ignited and almost completely vaporised.

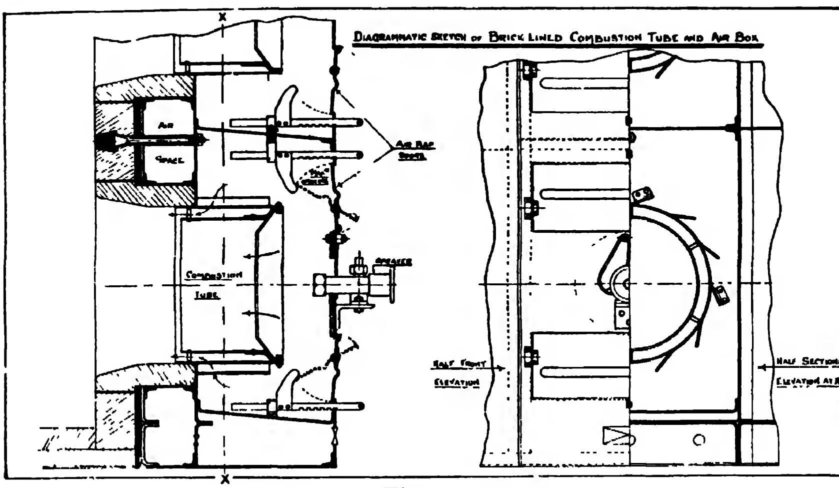

Fig. 3.

The latter method is illustrated in the diagram (Fig. 3), of a typical air box and combustion tube, from which it will be noted that the air under pressure from the boiler room is supplied through non-return flaps to the air boxes and thence to the furnace (1) through the centre of the tube with the oil spray and (2) through suitable slots at the furnace end of the tube, which give a rotary forward motion and materially assist in the intimate mixing of the oil and air. This arrangement also permits of control of the air both as to quantity and relative position to the spray. The restriction or flame ring fitted at the entrance to the combustion tube has the effect of causing the flame to curl back and fill up this space, so keeping the tube at the correct temperature to vaporise and ignite the oil.

It will be noted that the furnace end of the tube is protected from burning away by special bricks and that means are provided for sighting the flame and for clearing any accumulation of carbon from

the cone mouth. It will also be noted that the inlet shutters are arranged to act as non-return valves, preventing any back-flash or momentary excess of furnace pressure from blowing the flame back into the boiler room. The ideal air supply required at any part of a combustion tube is difficult to decide upon theoretically and has been arrived at experimentally.

Rates of burning as high as 1,200 lb. per hour in a 17·5-in. diameter tube have been efficiently maintained with this type.

The other system of burning referred to above, which might be called "furnace burning" for want of a better expression, has its advantages and disadvantages and is generally used in the Mercantile Marine. The oil enters the furnace as oil and, therefore, takes longer to burn, necessitating a relatively large combustion chamber and prohibiting high rates of forcing of the boiler. It has the advantage, however, that a relatively poor quality oil can be burned and that water up to 2 per cent. causes very little inconvenience.

For naval work, however, where it is necessary to obtain the maximum power from a given weight of boiler and given size of combustion space, it is imperative that a high rate of forcing can be attained; actually the maximum rate of forcing is usually about two or three times that normally found in the Mercantile Marine, the high speed of combustion required being made possible by means of the hot tube.

Oil fuel containing less than 0·5 per cent. of water is essential in this case, as water in the spray tends to cool the hot tube, slows up the speed of combustion and causes other difficulties which will be described later; an excessive quantity of water may even extinguish the flame in the hot tube.

PULSATION

One of the most important of the several factors which determine the upper limiting rate of burning oil efficiently, *i.e.*, with as high an oil temperature and as low an air pressure as possible, is the phenomenon commonly known as "pulsation." This, as its name suggests, is a vibration or pulsation of the flame comprising what amounts to a series of periodic explosions as compared with the steady burning desired. In practice it is liable to cause considerable damage to the furnace brickwork and casings and tends to discomfort the personnel.

This action is by no means fully understood, but any disturbance (particularly if of a periodic nature) of the steady flow of air or fuel to the furnace may be sufficient to cause instability.

Irregular working of the oil pumps may thus be a contributory cause and air vessels are fitted on the discharges to counteract this; in some cases rotary fuel pumps have been fitted. For this reason also, on the delivery side of reciprocating pumps, an adjustable spring-loaded relief valve is fitted which allows a definite delivery pressure to be maintained, the surplus oil being returned to the pump suction, the pump being run at a slightly excess speed so as to prevent fluctuation of pressure for slightly varying output.

Unsuitable types of fan impellers may also give discontinuous and periodic air flow at high speeds, as may also irregular working of fan engines and obstructions in the air path.

Other conditions which undoubtedly tend to promote pulsation are:—

(1) Unsuitable position and design of air inlet to the spray.
(2) Insufficient air supply.
(3) Too high a temperature of the oil.
(4) Presence of water in the oil.

The methods of maintaining the air supply vary according to conditions and requirements. Natural draught is suitable in cases where great heights of funnel are permissible and where a high rate of burning is not desired, but where the contrary is the case fans must be installed.

In general, the air supply for forced draught is provided by two methods, the closed stokehold and open stokehold with air casings. The former method has been generally adopted in the Royal Navy, pressures of about 2 in. to 3 in. of water being normal, but going up to 6 in. in torpedo boat destroyers where funnel height is limited and higher rates of forcing are used.

Details of the various types of fans used for this purpose would require more space than is permissible in this paper, but it may be of interest to remark that considerable attention has recently been paid to questions of reducing resistances in the air supply circuit. Where possible, all obstacles have been removed, unavoidable gratings, etc., stream-lined and sudden alterations in areas and directions avoided. This has resulted in a considerable reduction in the fan power necessary.

Air Pre-heating

Considerable gains in efficiency are now being obtained by air pre-heating or by supplying heated air to the burners, for besides enabling some of the direct funnel heat loss to be avoided, the heated air helps in the rapid combustion of the oil.

Many different designs of air heaters are in use and in most of these, as indicated above, the heat of the escaping funnel gases is used to heat up the air supply to the furnace; the heat radiated from the back of the brickwork may also be utilised for this purpose. Care must be taken not to restrict the area of the uptake passage or the area of the air inlet, as the extra pressure then required to force the air into the furnace, with consequent increased consumption of the fan engines, may counterbalance the increase in efficiency gained by the heating of the air supply.

COMBUSTION CHAMBER

The size, correct proportioning, and the insulation of the combustion space are the next factors to be considered.

The length of the furnace is not controlled as in coal firing by the ability of the stoker to throw coal, but rather by allowing the oil sufficient time in which to burn, thus ensuring that the maximum amount of heat is obtained from the fuel burning in the combustion space. This question of a time limit is of the utmost importance and is one which is but little understood, although the work now proceeding in the development of burning pulverised fuel, where it is of even greater importance, has brought this problem acutely to the fore.

It is usual to state the limiting rate of burning in a given furnace in terms of so many pounds per cubic foot of combustion chamber volume, a custom which gives rise to the idea that volume is the prime factor. In point of fact there is a minimum distance which must be provided for the travel of each particle of fuel if proper combustion is to be obtained. Any attempt to reduce this minimum results in poor efficiency, coupled with other practical drawbacks. Similarly, though not to quite the same extent, the provision of a furnace length much beyond the length necessary for complete combustion will reduce efficiency. The volume and length of the furnace are related to the area of the front and, as all types of oil fuel burners require very similar areas of front per pound of oil, it is evident that both volume and length per unit weight of fuel will be closely related in all installations.

Evidence is not wanting to show that the grade of oil exercises some effect upon the maximum possible rate of burning. Thus, Mexican oils appear to be somewhat slow burning, and cannot be burned so efficiently at high rates of forcing for a given furnace volume as other fuels.

In practice, the furnace proportions must also be considered, not only with a view to obtaining satisfactory combustion, but also with a view to exposing sufficient heating surface to the burning fuel and thus to the effect of radiant heat, while ensuring that no part is subjected to undue heat stresses.

The better utilisation of the furnace walls, with a view to increasing the amount of heat that may be absorbed at the maximum temperature head available, is a subject that has been and is, receiving an increasing amount of attention, as it appears that by such means the output of boilers of a given size may be somewhat increased.

A general allowance is now made of 10 lb. of oil per hour per cubic foot of combustion space. This is the generally accepted maximum rate with present devices, although higher figures have been accepted with sacrifice of efficiency.

FURNACE BRICKWORK

With the high temperature obtained in oil-fired furnaces, the question of a suitable refractory lining is of great importance and a large amount of experimental work has been necessary to ensure satisfactory refractory materials and methods of attachment to the boiler casings which will meet the conditions obtaining in highly forced boilers. The requirements for a satisfactory refractory material may be summarised as follows:—

(1) Good refractory and insulating qualities combined with reasonable weight and cost.
(2) Ability to withstand a sustained furnace temperature of about 3,000°F. without fusing, cracking, flaking, or undue expansion.
(3) Ability to stand rapid changes of temperature or vibration caused by pulsation, gunfire, etc., without disintegration.

Refractory bricks, which will meet all requirements, have been gradually evolved. Under normal circumstances modern brickwork should last for considerable periods without renewal or large repair, assuming that it has been properly built and has received proper care.

To ensure satisfactory material, specifications for best quality fire-resisting and insulating material and for fireclay, have now been drawn up which include definite tests to which the materials are subjected before acceptance.

The usual specified requirements include the following:—

The firebricks, tiles, etc., should be made of the best fire-resisting insulating material, should be of good sound quality and capable

of withstanding a temperature of 3,000°F. without flaking, cracking, glazing, shrinking, distortion or fusing.

No brick or tile which exceeds the specified dimensions by 1 per cent. or falls below them by 1·5 per cent, should be accepted.

The material should be evenly burnt throughout and the texture regular. There should be no holes or flaws and all surfaces should be reasonably true. The bricks or tiles should be capable of withstanding reasonable cutting or shaping when cold, without cracking or breaking. The density should correspond with a weight of not less than 115 lb. per cubic foot.

The material of the brick should be capable of sustaining a vertical crushing load of 1,800 lb. per square inch applied to the whole brick when placed on its edge.

Special attention must also be given to the method of building and securing the bricks, and to the bonding material.

Brickwork is so built that the joints between the bricks are as thin as possible, and the bonding material must not exceed $\frac{3}{16}$ in. in thickness.

All brickwork with the exception of that on the bottom of the furnace is secured by bolts. The brickwork on the bottom of the furnace is arranged in two layers.

When bricks are held in place by bolts, the bolt heads or nuts must be in a recess, which is afterwards filled with a suitable stopping. If the bolt head becomes exposed it will very soon burn away and if fused may form, with the material of the brick, a compound of comparatively low melting point which, in running in a melted condition, will cut channels in the brickwork. To avoid this it is essential that the stopping should be of the right mixture and carefully applied.

The most satisfactory bonding and stopping material has been found to be a mixture of crushed firebrick and fireclay in equal parts.

Bolthead stopping in brickwork is, however, always liable to become loose, and a new method of securing brickwork has accordingly been devised, in which the head of a special type of bolt is fixed into a recess in the back of the firebrick. This method gives promise of improved durability of the brickwork.

To assist in insulating the furnace walls, a layer of asbestos millboard not less than $\frac{3}{8}$ in. thick is fitted between the bricks and the plating, to which the brickwork is secured or on which the brickwork rests.

STORAGE AND HANDLING

All possible precautions must be taken to prevent leakage from oil fuel tanks and special close riveting is adopted when the tanks are being built, a water-test pressure of 10 ft. head above water line being finally applied.

In order to allow free expansion and proper ventilation below the deck beams, oil-fuel tanks are never filled to above 95 per cent. of their full capacity.

Proper vent pipes are necessary and are usually fitted in duplicate at the highest parts of the tanks leading to some point on the upper deck, where the vapour cannot be accidentally ignited; gauze wire is fitted to the outlet ends. This point is of considerable importance since oil vapour is the greatest source of danger.

Roughly 9 per cent. of oil vapour is required in air for the formation of an explosive mixture. Actually, it is unusual for more than 0·04 per cent. to be found in oil tanks at the ordinary temperature.

Oil bunker bulkheads and double-bottom tank tops must also be at a reasonable distance from boiler casings and brick pans; usually 18 in. is taken as the minimum distance allowable.

Special locks should be provided for filling and suction valves, which latter should be of the non-return and screw-down type; the keys of these locks, together with any special spanners for opening manhole doors, should be kept in safe custody.

The vapour from oil fuel is so heavy that it is not easily displaced by ordinary ventilation. Before any oil-fuel compartment is to be entered, it should be completely flooded with sea water, this operation being repeated as often as necessary to displace these vapours entirely. The presence of inflammable gases can be detected by using a safety lamp. On no account should a naked light be used where there is any possibility of presence of oil vapour.

If the above precautions are observed the risk of fire in oil fuel installations can, to a large extent, be obviated, providing that proper precautions are taken in the operation of the burning equipment and in preventing leakages and accumulations of oil in bilges, air boxes and stokehold plates. It should be noted here that the most common causes of oil fuel fires in the past have been the fracture of, or leakage from, the oil fuel pressure pipes between the heaters and the boiler, the resulting spray of hot oil readily igniting on striking the boiler front. Solid drawn steel is specified for these pipes, and all joints must be faced metal to metal.

For filling oil fuel tanks a special system of pipes should be fitted. Oil can usually be transferred from one tank to another to correct heel or trim or for any other purpose by means of the oil fuel pumps.

Special sounding tubes are fitted to the tanks and sounding accomplished by lowering graduated steel tapes down the tubes. As in the case of the vent pipes the greatest care is necessary to avoid naked lights being brought in their vicinity, more especially during the filling of tanks when vapour is driven out. Sounding by the pneumercator method has also been fitted in some cases where tanks are inaccessible and sounding tubes cannot be utilised.

Any water or sediment accumulating in the tanks should be removed by means of special suctions fitted to the lowest part of the tanks. These residue suctions should be connected to the fire and bilge pumps or to portable hand pumps by means of hoses. Sensitised paper or electrical instruments are frequently used for detecting the presence of water.

Heating coils are usually fitted in the tanks and also round the end of the suction pipes in the tanks, to enable the more viscous oils to be utilised. Heating arrangements are sometimes fitted to suction pipes outside the oil fuel tanks also. Before warming oil in these pipes the necessary valves should be opened to prevent undue accumulation of pressure due to expansion of the oil.

Oil circulating arrangements are also fitted, so that when lighting up oil can be heated by circulation through the heater, provided steam is available from another boiler. Thermometers are fitted on the common oil fuel delivery pipe on the boiler fronts.

Care is necessary in order to avoid overheating of oil in the tanks and steam should not be used unless the coils are well covered by the oil.

SEPARATION OF WATER AND OIL.

The extensive use of petroleum products introduces the problem of how to deal with the handling and disposal of oil-contaminated water and waste, such as ballast and bilge water, consisting largely of a mixture of oil and water in an emulsified form, in which state their separation becomes very difficult.

The ideal is to recover the oil in such a form that it can be used as a fuel, leaving the separated water sufficiently pure for discharge into the sea without infringing the regulations as to the contamination of harbours and other territorial waters. A very small quantity of heavy oil will cover a large area; besides its other objectionable features, shown for instance when washed up on shore, it is harmful to fish and bird life.

Heating the mixture of oil and water assists the separation by the action of gravity, but for complete separation a properly designed separating plant must be utilised. There are many types of separators available, centrifugal, for dealing with small quantities, and adaptations of the gravity system for dealing with large quantities by means of an extended series of baffles and chambers, designed to assist as far as possible the natural settling out or separation of the oil from the water. Several types of the latter have been fitted in oil-separating barges or in ships' tanks, which deal with large volumes and give remarkable purity of discharge.

The use of fuel oils for railways and on shore, where it is realised great advance has been made, has not been dealt with in this paper, but it is hoped that the information given will be of general interest to the Conference.

RÉSUMÉ

En discutant la question de l'utilisation des combustibles liquides à la production de vapeur au point de vue de son application à la navigation maritime, le mémoire comporte les sections suivantes

(1) Histoire du développement par rapport spécial à la Marine de guerre anglaise; résumé des avantages que comporte l'utilisation de l'huile sur l'emploi du charbon.

(2) Convenance et traits charactéristiques des divers combustibles liquides, y compris les qualités à désirer. Sont mentionnés: le pétrole, l'huile de schiste, l'huile de houille et les combustibles colloïdaux.

(3) Combustion des combustibles liquides, divers systèmes de pulvérisation, d'alimentation d'air, de pulsation, de chauffage préalable de l'air et de briquetage du foyer.

(4) Emmagasinage et manipulation, y compris les précautions à prendre pour éviter les incendies, etc.

THE BURNING OF POLISH COAL ON LOCOMOTIVES

POLISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

STANISLAW FELSZ

Paper No. J8

CONTENTS

In order to explain the behaviour of Polish (Dąbrowa basin) coal in boiler fireboxes and to compare it with Russian (Donetz) and British (Yorkshire and Newcastle) coal, train experiments were carried out on one engine; these experiments provided material for a detailed analysis of combustion and for the comparative characteristics of Polish coal.

More than eighty test runs were carried out on a sector 125 kilometres long, and with varying gradients, so that the quantities of coal burnt per unit grate area and other results of each test run must be considered as being average ones, while fluctuations occurred between fairly wide limits. Approximately sixty runs were carried out with an arch in the firebox, using all kinds of coal, and approximately twenty runs without an arch, using two kinds of coal.

The Establishment of Maximum Efficiency of the Boiler

It is common knowledge from experiments with railway engines that the highest efficiency of the boiler depends to a considerable extent on the quantity of coal burnt per unit grate area, and decreases

in proportion to the increase of the quantity. It has also been ascertained that the values of the highest attainable efficiency, the so-called *best efficiency*, at medium and high rates of combustion, form a straight line which may be expressed by the following general formula:

$$\eta = \eta_o - \beta b,$$

where η_o and β are constant factors dependent on the construction of the boiler and on the value of coal, whereas b represents the quantity of coal burnt per unit grate area in Kgs. per sq. metre.

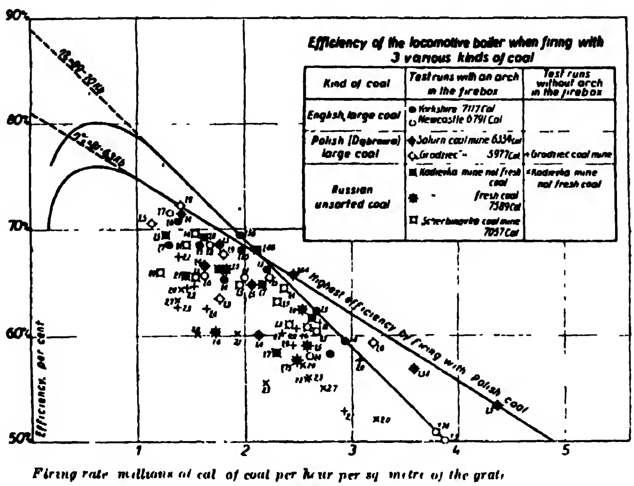

Fig. 1.

Fig. 1 provides a summary of factors of the attained efficiency of the boilers as a function of the quantity of coal burnt per unit grate area, whereby in view of the varying heating value of coal used for the experiments (K = 6,000 to 7,600 calories per Kg.) the quantity of coal burnt per unit grate area was expressed in millions of calories burnt (Kb). The results of these tests enable us to represent the relation between the best efficiency of the boiler and the quantity of coal burnt per unit grate area for Dąbrowa coal by a straight line corresponding to an equation

$$\eta\,\% = 81 - 6{\cdot}3\,Kb.$$

On the entire length of this line, there are the results of tests carried out with Dąbrowa coal, from a load of 1·4 *to* 4·4 *million calories.* Assuming "standard coal" to correspond to a heating value of K = 6,300 calories per Kg., it is possible to establish, on the basis of these experiments, in round figures the equation

$$\eta\,\% = 80 - 0{\cdot}04\,b_{\iota}.$$

as the simplest formula of the so-called best efficiency of the boiler,

when burning this kind of coal (Polish-Dąbrowa) under an arch (b_n denotes here the quantity of coal burnt per unit grate area in Kgs. of standard coal). Runs without an arch were not frequent, though it is apparent that the best test results *with Dąbrowa coal, using equal quantities of coal burnt per unit grate area, exceed the best test results with run-of-mine Russian coal.*

The Rôle of Excess Air

A detailed analysis of the above experiments brought the writer to the conclusion that *for each individual quantity of coal burnt per unit grate area there exists a certain most satisfactory excess of air, with which the highest boiler efficiency can be obtained.*

This most satisfactory excess of air should be the least possible at low quantities of coal burnt per unit grate area, and considerably increases with the increase of firing rate. This is due to the quantity of sparks which increases with the increase of temperature of combustion and the firing rate.

The exhaustion of the boiler (overloading) under very high loads is the result of insufficient excess of air for the respective critical load.

A possible increase of this excess under high loads increases the efficiency and output of the boiler.

In reality—on the entire scale of possible quantites of coal burnt per unit grate area—an excess of air is obtained which differs from the most favourable one: under low load it is higher, whereas under high loads it is lower than the most favourable one, and it is only under medium loads, and with an arch, that the most satisfactory excess of air is obtained.

It therefore follows that *at low quantities of coal burnt per unit grate area the excess of air should, wherever possible, be throttled, whereas at high loads it should be increased.*

For the purpose of guidance as to the excess of air obtained, the indices are given in Fig. 1, at each point showing efficiency, denoting the average excess of air for each test. In the majority of cases these figures are rounded off to the nearest decimal point.

It is striking that even the short arch (0·6 metres) offers a considerable resistance to the passage of gases, thus reducing the excess of air obtained.

A better illustration of the excess of air is provided by the comparison of the draught with the quantity of gases of combustion passing through the boiler.

Draught and Mass of Gases of Combustion

From the analysis of coal combustion on the basis of the above tests, calculations were made of the gas mass, allowance being made for unburnt coal and volatile matter.

The draught resistances were also known. Each mm. of water gauge which records the rarefaction (partial vacuum) in the smoke-box (under the spark screen) corresponds to 1 Kg. of resistance of the mass of air and combustion gases formed per sq. metre of grate and drawn through the boiler.

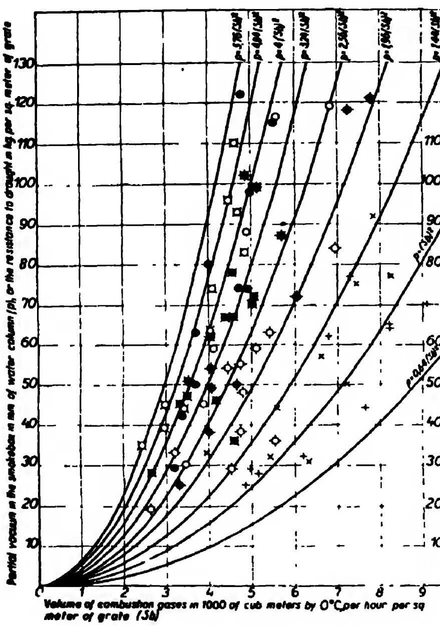

Fig 2

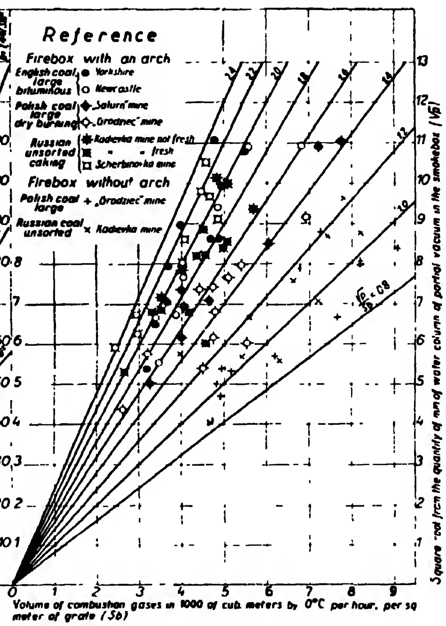

Fig. 3

The volume of the mass of gases formed per sq. metre of grate per hour, reckoned in cu. metres, relative to 0°C. temperature and a pressure of 760 mm., simultaneously expresses in figures the vertical component of the velocity of flow of the gases through the firebox in metres per hour at 0°C. and 760 mm.

In one and the same engine this velocity corresponds to the greater velocity of flow of the air between the fire bars and of flow of the gases through the fire tubes.

When using various kinds of coal or various installations influencing the resistance to draught, the respective volume of flue gases and thus also the velocity of flow must vary in accordance with the resistances which are produced by the particular installation,

together with the layer of live coal and of clinker foundation of the particular coal.

In Fig. 2, on the axis of the abscissæ, we have the rarefaction in the smokebox estimated according to the volumes of gases (Sb) in thousands of cu. metres (= cu. dekameters) at 0°C. (760 mm.) obtained per sq. metre of grate per hour. The resistances of the draught must be proportional to the square of the velocity of flow of the gases, *i.e.*, they must be proportional to the square of the volume of the combustion products (Sb^2).

In this diagram, curves are shown representing the draught (p mm.) as a function of the square of the volume (Sb dkm.^{3})^2, by the same constant factors, commencing from $p = (0.8\ Sb)^2$ and ending with $p = (2{\cdot}4\ Sb)^2$.

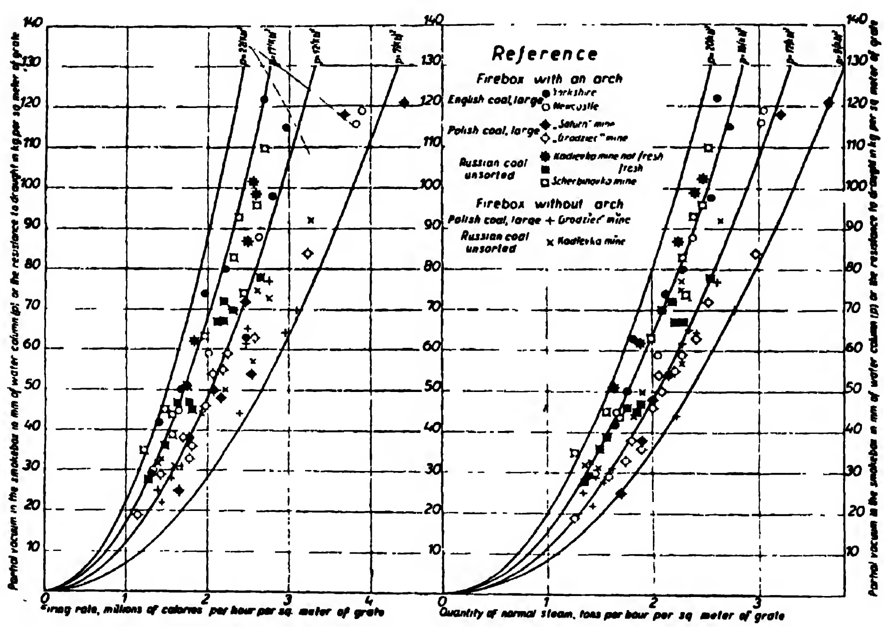

Fig. 4.

Fig 5

In Fig. 3, where the square roots of the rarefaction value ($\sqrt{p}$) are plotted against the volume of combustion gases, we have the functional relation $p = f(Sb)$ represented by a bundle of straight lines, radiating from $Sb = 0$.

Resistance to Draught and Excess of Air

One and the same draught produces a varying flow of the mass of gases, dependent upon whether an arch is available and also on the kind of coal.

Figs. 2 and 3 show the influence of the arch and of the various kinds of coal. The least resistances in the flow of gases are obtained in the absence of an arch (on the average, $p = Sb^2$).

Under the arch (0·6 m.) the least resistances are produced with dry Polish (Dąbrowa) coal (on average $p = 2Sb^2$), these being followed by Russian (Donetz) and British caking coals. This difference may partly be attributed to the caking properties of the coal and partly to the varying porosity of the clinker layer. The higher percentage of free oxygen contained in the Dąbrowa coal probably also has a certain influence.

Similar differences also occur in Figs. 4 and 5, where the draught is plotted against the quantity of coal burnt per unit grate area in millions of calories consumed (Fig. 4) and against the required quantity of steam per sq. metre of grate per hour (Fig. 5).

Therefore, with an equal quantity of steam required per sq. metre of grate, the non-caking Dąbrowa coal, with an almost non-fusible ash and yielding a porous clinker, shows easy combustion under relatively low resistances of draught, thus requiring smaller counter-pressure on the pistons.

For instance, at a required average quantity of steam of 2,000 Kg. per sq. metre of grate per hour a draught equal to 36–48 mm. pressure of water column is sufficient for Dąbrowa coal, whereas in the case of caking coals the draught must be increased to 48–80 mm. and, under equal working conditions, dry coal gives a more considerable flow of gases through the boiler per sq. metre of grate.

The mass of gases is proportional to the quantity of coal burnt per unit grate area and to the excess of air.

Thus, with equal rates of firing and draught, the dry Dąbrowa coal burns with a larger excess of air than caking coal with easily-fusible ash and a compact layer of clinker.

The largest possible excess of air is necessary, as has been ascertained, for higher loads, and on it depends the increase of the limit of productive combustion. This explains the higher elasticity of evaporation from dry coal.

LIMIT OF COMBUSTION AND THE ELASTICITY OF THE BOILER.

From the formula for the best efficiency of the boiler $\eta\% = 81 - 6{\cdot}3Kb$ (*vide* Fig. 1) we are able to determine the limit of combustion which occurs at the critical rate of firing $Kb_k = \frac{81}{2 \times 6{\cdot}3} = 6{\cdot}43$ millions of calories, which corresponds to over 1,000 Kg. of Dąbrowa

coal per sq. metre of grate per hour. At a critical efficiency of 40·5 per cent. this corresponds to more than 4,000 Kg. of normal steam per sq. metre of grate per hour (*vide* Fig. 6). It may be assumed that such a large temporary amount of coal burnt per unit grate area was reached when running on Polish coal from the "Saturn" mine at an average *Kb* value of 4·4 million calories.

The ease of obtaining the highest excess of air, i.e., the facility of efficient combustion of such large quantities of Polish coal, *is a most valuable property under the heavy and varying work of the locomotive boiler which, particularly on gradients, must make a considerable and fairly continuous effort.*

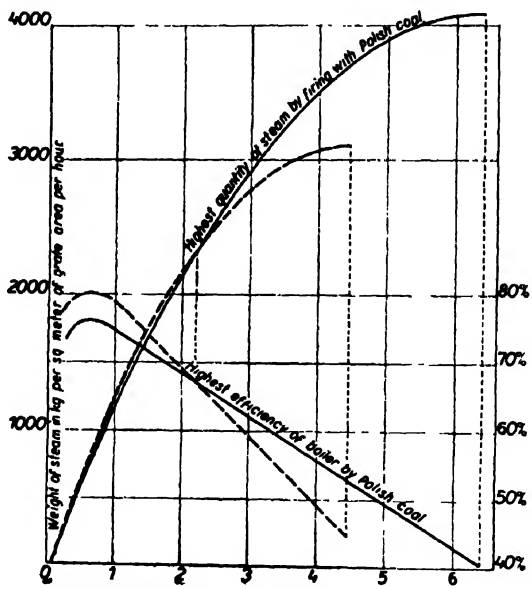

Fig. 6.

Even when using the largest grates for hand firing (4·5 sq. metres) *the standards of train loads are dependent on this temporary effort.*

High standards of load require a reduced consumption of coal per 1,000 *ton-kilometres of load carried.*

They thus produce an actual economy in coal.

This property of Polish coal facilitates making up for train delays, particularly in the case of passenger and heavy express trains, provided the maximum speed limits fixed for the trains (in consideration of the carrying capacity of the track) *do not interfere.*

This natural ease of allowing a larger excess of air to be passed with large quantities of coal burnt per unit grate area cannot easily

be replaced by additional forced draught under the grate or between the fire bars.

In the case of medium and small quantities of coal burnt per unit grate area, this ease of attaining larger excess of air becomes a defect which, however, may easily be overcome by throttling the excess of air.

This is achieved by ordinary and economic means tending to increase the resistance of draught: by selection of smaller and thus cheaper kinds of coal (nuts and mixture), by longer arches, by choking part of the grate down to the most economic area in view of waste combustion (which increases the quantity of coal burnt per unit grate area of the working boiler), by reducing the width of the air-spaces between the fire bars, etc.

SELECTION OF COAL.

The smaller kinds of coal, run-of-mine coal or mixture, are cheaper than the larger kinds.

The calculation of cost depends, as is known, on the calorific value and transport cost reckoned by distance. The calculation of the useful value of the finer kinds of fuel (nuts and mixture) was effected by means of experiments.

Tests showed that even *the non-caking Polish (Dąbrowa) mixture without classified larger coal is very profitable for shunting engines,* whereby the mixture has to be moistened and must be fed in small heaps, loosely; spreading over the grate with the throttle valve open produces considerable losses in raw coal dust carried into the chimney.

At an extra cost of transport and storage and delivery to the engine reckoned at 50 per cent. of the loco. mine cost of larger coal, the total cost of lump coal was 25 per cent. higher than the cost of mixture. When shunting, the most economic quantities of coal burnt per unit grate area of 60–80 Kg. per sq. metre of grate per hour for lumps and of 50–60 Kg. for mixture, the steam obtained with mixture proved to be on average 15 per cent. cheaper than that obtained with lump coal.

With an increase in the quantity of coal burnt per unit grate area on the lighter type engines, the profitable calculation of the mixture declined and disappeared entirely at a working load per unit grate area of over 300 *Kg.* (1·9 *million calories*).

For train haulage large and lump coal is used with a compulsory addition of nuts.

In the case of one railway district, for instance, where for train haulage mainly Dąbrowa coal is consumed, the compulsory addition

of nuts amounts to 25 per cent. for long-distance passenger trains and 50 per cent. in suburban passenger and long-distance goods trains—in these latter at large grate surfaces, of up to 4·5 sq. metres, the nuts being mainly intended for runs with empty trucks.

In order to encourage the engine drivers to increase the use of cheaper kinds of coal, they are taken at a cheaper rate with regard to the premium than the calculation shows, the so-called calculation factors being used, namely the factor 0·9 *or* 0·8. Ten cubs of nuts are reckoned as nine cubs of larger coal and, for mixture, ten cubs of mixture are reckoned as eight cubs of large coal, the factor for mixture having a value of 0·8.

Cracow coal, of a lower calorific value and higher percentage of ash, burns well and is profitable in shunting operations, even farther away from the coal district, provided the price is low enough.

ARCHES

Arches are used in all locomotives without exception.

The longer they are, the greater resistance do they provide to the draught.

A few years ago there was still some hesitation as to the utility of erecting arches in the fireboxes of locomotives with small working load. *Experiments have proved the undeniable usefulness of long arches* (1·2–1·35 *metres*) *at small quantities of coal burnt per unit grate area.*

In suburban passenger trains, at a firing rate of 250 Kg. of coal per sq. metre per hour, a long arch (1·2 metres) gave approximately 5 per cent. saving, as compared with a short arch (0·6 metre).

On shunting engines a long arch (1·35 metre) gave a higher percentage of saving (8-11 per cent.) when burning lump and nuts, whereas when burning mixture the saving was only 4 per cent. Small arches provided moderate savings with all kinds of coal.

This becomes evident from the point of view of increased resistances to the flow of the excess of air

At larger quantities of coal burnt per unit grate area, shorter arches are adequate.

Arches in all cases provide better maintenance of smoke tubes, reducing the number of leakages.

The main advantage of arches is obtained through the reduction of the loss due to the formation of carbon monoxide (CO).

The elongated path for the flames under the arch allows for better development of the flame, and in this respect is equivalent to an increased capacity of firebox.

The arch itself maintains a sufficiently high ignition temperature for good combustion of any carbon monoxide, but the temperature is insufficient for burning hydro-carbons, particularly heavy ones.

Combustion of Hydro-Carbons and Method of Stoking

Hydro-carbons of Polish coal are easily combustible, provided during combustion the coal is fed frequently in sufficient quantities required by the rate of firing, but not exceeding 40 Kg. per sq. metre of grate. Such quantity in lumps covers approximately half of the surface of the grate. At high loads, for instance, 800 Kg. per sq. metre of grate per hour, such quantities should be fed every 3 minutes $\left(\frac{60}{3} \times 40 = 800\right)$.

At small quantities per unit grate area, for instance 100 Kg. per sq. metre per hour, quantities of 1–2 shovels (8–16 Kg.) per sq. metre of grate, fed every 5–10 minutes, are sufficient.

It is necessary not only to feed fresh coal uniformly and loosely on to the surface of the burning coal, but also to maintain a continuous and uniform flame by means of frequent stoking. This is particularly important when small quantities of coal are burnt per unit grate area.

If the burnt spaces (or those covered with clinker) are not visible through the flame, it is necessary to start to cover the grate from rear to front (*i.e.*, from the fire doors to the tube plate).

In general, the fireman should feed the coal at such intervals that the combustion of volatile matter should not occur after closing the throttle valve.

With such a system of stoking, secondary air may only be necessary at higher combustion rates, particularly if only the front ash pan damper is open. In the absence of arrangements for secondary air in locomotives, it is sufficient in such cases to slightly open the fire doors, so that the smoke assumes a light-grey colour, closing them as soon as this slight hue has disappeared.[1]

Safety from Fire

Unburned hydro-carbons of Polish coal contain but a small proportion of tar components.

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[1] Recently, individual tests have been carried out with the Langer nozzle, which directs a jet of steam into the centre of the flame field. A saving in coal of approx. 10 per cent. (net) was obtained. In view of this, the apparatus under reference is qualified for further tests to be carried out with half of the entire engine groups.

This property is illustrated by *the possibility of fitting fine (narrow-meshed) spark-arresting nets (in the smoke-box).* With the nets previously used, of square mesh 5–10 mm., the sparks could still ignite dry gorse, loads of hay and other dry materials. This type of net has been replaced a few years ago by one with a longitudinal mesh 3 × 10 mm., the mesh being arranged vertically in longitudinal section so that sparks cannot deposit in the net.

The caking Russian (Donetz) coal did not permit the introduction of such nets: soot and sparks, stuck together by tar, soon clogged the openings entirely, whereas *in the case of Polish coal fine nets have been widely used by the Polish State Railways and have given no particular trouble*, particularly nets of large surface.

GRATE AND FIRE BARS

For Polish dry coal, the air spaces between the bars should not exceed 12 mm. On a large number of shunting engines comparative experiments have been carried out with fire bars of 20 25 mm., with a space reduced from the average 13 mm. to 8 mm., and showed an increased evaporation capacity of the coal, by 4 6 per cent. No difference in saving between lump and mixture coal has been detected.

These experiments were numerous and gave similar results. The reduction of the air space below 8 mm. creates greater difficulties in clearing the fire bars.

It may be added that for heavier work with Upper Silesian and Dąbrowa coal and for all classes of work with Cracow coal (with a higher percentage of ash) tipping or drop sections in the grate have been found very useful for easy cleaning of the grate from excessive deposit of clinker.

WASTE COMBUSTION AND GRATE AREA

In the operating of railways one has to seriously reckon with the waste combustion of coal during engine stops and during runs with closed throttle valve (for maintaining steam and fire). To this must be added the lighting up of the fire in the boiler. Dependent on the size of the grate and on the nature of traffic, a working engine has a waste combustion of 250 to 900 Kg. of coal per day, which represents 10–50 per cent. of the total quantity of coal burnt in the course of work.

The quality of coal herein plays a secondary role. The question of waste combustion and insulation losses has been considered by means of experiments carried out under the supervision of the write~, and results will shortly be published.

There are simple remedies which can considerably reduce waste combustion in general.

In addition to this, it is easy to estimate the most economic grate area at which the total coal consumption, burned during working hours and wasted, would be the smallest under the individual work the engine has to perform.

To this most economic grate area corresponds the most economic quantity of coal burnt per unit grate area, under working conditions or per 24 hours.

With regard to working conditions on the Polish State Railways, the most economic grate area fluctuates between 1·2 and 4·5 sq. metres.

We may add that tests carried out with shunting engines have shown the highest evaporative efficiency of non-caking mixture, at an average rate of firing, to be 50–80 Kg. per sq. metre of grate area per average hour, whereas if nuts and lumps be used (with a heating value of 6,300 calories) it is 60–80 Kg. per sq. metre of grate area per hour.

The fluctuation between 50 and 80 depends upon the intensity of the work of the engine.

These experiments only go to prove the assumption previously made on the basis of theoretical train experiments.

On the basis of these optimal quantities per unit grate area it is possible to estimate the most economic grate area for shunting.

For train service, the most economic quantity of coal per unit grate area and the most economic grate area may easily be estimated from the load of waste combustion per working hour of the boiler.

A grate which is larger than the most economic may be partly choked under uniform work, or in such event larger quantities of the lower grades of coal may be burned thereon.

Under irregular working conditions, for instance with a train carrying in one direction a load of 2,000 tons and returning empty under a load of 600 tons, suitable coal may be selected: lump for the run with load and mixture or nuts for the run without load.

Span and Volume of Firebox

Considering the small volume of the firebox per sq. metre of grate, the proper development of the flame and combustion of gases may be partly achieved by means of an arch of a suitable length. However, the suitable utilisation and absorbtion of the heat by radiation of the burning layer of coal and of the flame is at a disadvantage in fireboxes of small capacities.

The arch tends to increase the temperature of combustion, but usually does not increase the absorbing capacity of such a furnace.

This capacity is dependent on the ratio of the heating surface of the furnace to the grate area $h_p = \frac{H_p}{R}$, which we term the span of the furnace.

It is easy to realise that $h_p = 1 + 2h\left(\frac{1}{l} + \frac{1}{a}\right)$, where h = height, l = length and a = width of firebox.

For possible increase of the grate area and the reduction of the load of the boiler, fireboxes are at present being carried above the frame in order to increase the width of the furnace (a).

The raising of the grate automatically causes the reduction of the height of the firebox (h).

Thus, at present, the span is reduced owing to the reduction of the height h and the increase of the width a.

Whereas in engines having a firebox between the frames the span usually exceeded 5 and reached up to 5·5, the span in engines with a large grate carried above the frame fluctuates between 3·5 and 3·8.

This deficiency may probably be equalised by means of the combustion chamber.

In this direction, so far only tests have been initiated.

In addition to these important factors there still remain a number of lesser ones.

SUMMARY

The results of Polish locomotive experiments may be summarised as follows: *dry coal* (non-caking or slightly-caking coals) *with ash which is not easily fusible and porous clinker are more suitable than rich coal for the work of boilers, where the draught is weak in proportion to the required working load of the boiler.*

Such conditions obtain with low chimneys of stationary boilers or with insufficient artificial draught, *i.e.*, with reduced cost of producing draught.

RÉSUMÉ

En se basant sur les résultats de plusieurs études expérimentales sur le chauffage des locomotives avec des houilles polonaises, anglaises et russes, l'auteur fait l'examen des conditions donnant la combustion la plus favorable de la houille polonaise sur les locomotives. Il envisage successivement l'influence de la voûte, le choix de l'excès d'air, la scorification, les grilles, les dimensions des chambres à combustion et la production des étincelles.

ESTIMATION OF HEAT LOSSES WHEN EMPLOYING NATURAL GAS AS BOILER FUEL

POLISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

WIKTOR WIŚNIOWSKI

Paper No. J9

CONTENTS

Heat losses occurring in boiler practice can be divided into two classes. The first includes the losses depending solely on the construction and design of the plant, while the second includes losses which, although not entirely unaffected by the design of the equipment, are mainly occasioned by the nature of the fuel. Heat losses in the flue gases, as well as those resulting from incomplete combustion, are included in this class.

In considering the hydrocarbons present in the gas and in the gaseous combustion products, it is convenient to denote the molecular proportions of carbon and hydrogen by the indices n and m respectively. The general formula for the hydrocarbon content thus becomes C_nH_m, a formula which, provided the ratio of the two elements only is considered, can be applied to any mixtures of hydrocarbons, hydrocarbons and hydrogen, and even hydrogen itself, besides individual hydrocarbons. Furthermore, when considering a mixture, it is possible to denote the physical properties of the combustible part of the gas, such as the calorific value, the density, the specific heat, etc., by the same indices.

The fact that Polish natural gas contains only paraffin hydrocarbons considerably facilitates the calculation of such values as the heat value. For paraffin hydrocarbons the relation between n and m is: $m = 2n + 2$.

For the present purpose, however, the formula C_nH_m will be used and will include both the hydrocarbons and the free hydrogen. Both indices vary progressively.

Other components of the natural gas to be considered are carbon monoxide, carbon dioxide, elementary oxygen and nitrogen. By making due allowance in the calculations for the presence of these substances, greater accuracy is attained and the calculations gain in value. Allowances must also be made for the products of combustion, which produce quite a definite effect.

Apart from the products of complete combustion, carbon monoxide, hydrogen, carbon and hydrocarbons are all found in flue gases. The heat losses resulting from the presence of hydrocarbons and hydrogen are not solely determined by the quantities remaining unburnt but also depend, to some extent, upon the indices, n and m.

HEAT LOSSES DUE TO THE PRESENCE OF UNBURNT CONSTITUENTS IN THE FLUE GASES

The general equation for calculating the heat losses resulting from the presence of unburnt material,

$$S = \frac{\text{cal. value, unburnt constituents in combust. products}}{\text{cal. value of natural gas.}} \cdot V_1$$

$$\cdot \text{ percentage of unburnt constituents,}$$

contains, apart from the values which can be determined by direct measurement, an unknown figure V_1, the volume of the gaseous combustion products.

The method for calculating V_1 is based upon the distribution of carbon or of oxygen before and after combustion, V_1 being given by the equation

$$V_1 = \frac{\xi + \eta + \zeta\eta}{w + x + y + 2n_1} \tag{1}$$

where V_1 = volume of dry combustion products per cubic metre of natural gas,

ξ = percentage of carbon dioxide in natural gas

η = ,, ,, carbon monoxide ,, ,,

ζ = ,, ,, hydrocarbons ,, ,,

n = carbon index in the general formula for hydrocarbons present in gas,

w = total carbon content of combustion products per 100 mols. in Kg. atoms,

x, y, z = percentage of carbon dioxide, carbon monoxide

and of hydrocarbons in the combustion products (determined by analysis)

and n_1 = carbon index for unburnt hydrogen—hydrocarbon mixture in combustion products.

As no allowance is made for the presence of free carbon in the gaseous combustion products, this formula can only be applied when no carbon ("soot") is formed. Free carbon is, however usually present in the products of combustion, and allowance for its presence must be made by using the equation

$$V_1 = \frac{8400 + (79m - 84\zeta) - [400(\xi + \theta) + 242\eta]}{8400 + (79m_1 - 84)Z - [400(x + t) + 242y]} \qquad (2)$$

where m and m_1 are the hydrogen indices corresponding to n and n_1,

θ = percentage of free oxygen in natural gas

and t = ,, ,, ,, ,, dry combustion products

This equation is obtained by calculating the proportion of oxygen in the fuel and in the atmospheric air used for combustion, as well as in the combustion products. Actually the oxygen supplied to the furnace is given by the expression

$$\frac{\xi + \theta}{100} + \frac{\eta}{200} + \frac{21}{79} \cdot \frac{V_1 a - \alpha}{100} \qquad (3)$$

where a = percentage of nitrogen in the combustion products

and α = ,, ,, ,, natural gas.

By taking into account the distribution of oxygen in the combustion products formed from 1 cu. metre of natural gas (at N.T.P.), the following expression is obtained for the oxygen present in the moist combustion products:—

$$V_1 \cdot \frac{x + t}{100} + V_1 \cdot \frac{y}{200} + \text{(oxygen present as water vapour)} \qquad (4)$$

Water vapour is, however, not formed in theoretical amount, as part of the hydrogen, either free or combined, contained in the fuel escapes combustion. This quantity is proportional to the index m_1. Hence oxygen in water vapour

$$= \frac{\zeta}{100} \cdot \frac{m}{2} - \frac{Z\ V_1}{100} \frac{m_1}{2} \qquad (5)$$

Equation (2) is obtained from these three expressions. The simplicity of this equation is due to the introduction of the indices for the hydrocarbons and hydrogen into the calculations. This also simplifies the procedure for analysing the combustion products

and the calorific value is obtained from the line $W - a$, the assumption being made that methane is the only other constituent.

Heat Losses in the Flue Gas

The heat losses in the flue gases are given by the equation

$$S_t = \frac{t_{sp} - t_O}{W_d} (V_1 x\, C_{mCO_2} + V y\, C_{mCO} + V_1 Z C_{mCnHm} + V_1 t C_{mO_2} + V_1 a\, C_{mN_2} + \frac{m}{2} \zeta\, C_{mH_2O} - V_1 Z \frac{m_1}{2} C_{mH_2O}) \quad (7)$$

where t_O and t_{sp} represent the corresponding temperatures of the boiler house and of the combustion products,

c_m = average specific heat within the limits of temperature t_O and t_{sp}

and W_d = the lower calorific value of the natural gas.

Now $C_{mCO} = C_{mCO_2} = C_{mN_2}$

and $y + t + a = 100 - x - 2$

also, for average temperature differences of 250°C.

$C_{mO_2} = 0{\cdot}442$
$C_{mCO} = 0{\cdot}318$
$C_{mH_2O} = 0{\cdot}376$

Inserting these values the equation becomes

$$S_t = \frac{t_{sp} - t_O}{W_d} \left\{ V_1[0.124x + (C_{mCnHn} - 0{\cdot}318 - 0{\cdot}188m_1) Z + 31{\cdot}8] + 0{\cdot}188\, \zeta m \right\} \quad (7a)$$

As in the case of the calorific value of a hydrogen-hydrocarbon mixture, the determination of the specific heat can be, in practice, reduced to the two possibilities, (*a*) when $n_1 < 1$ and (*b*) when $n_1 > 1$. The assumption is also made that only paraffins and hydrogen are present, so that $m = 2n + 2$ and $m_1 = 2n_1 + 2$.

(*a*) $n_1 > 1$

In this case, as before, the assumption is made that no free hydrogen is present in the combustion products. It is also assumed that

$$C_{mCnHm} = C_{mCH_4} = 0{\cdot}451.$$

The equation then becomes

$$S_t = \frac{t_{sp} - t_O}{W_d} \left\{ V_1 [0{\cdot}214x - (0{\cdot}243 + 0{\cdot}376n_1) Z + 31{\cdot}8] + 37{\cdot}6 (n + 1) \right\} \quad (8)$$

(b) $n < 1$

The assumption is made that only methane and hydrogen are present. The specific heat of such a mixture is given by

$$C_{mC_nH_m} = n_1 C_{mCH_4} + (1 - n_1) C_{mH_2} = 0{\cdot}317 + 0{\cdot}134 n_1 \qquad (9)$$

where $C_{mCH_4} = 0{\cdot}451$

and $C_{mH_2} = 0{\cdot}317$.

By inserting these values the equation becomes

$$S_i = \frac{t_{sp} - t_0}{W_d} \; V_1 \left[0{\cdot}124x - (0{\cdot}377 + 0{\cdot}242\, n_1)\, Z + 31{\cdot}8 + 37{\cdot}6 \right. \\ \left. (n + 1)\right] \qquad (10)$$

In the event of complete combustion occurring, the equation giving the heat losses in the flue gases becomes

$$S = \frac{t_{sp} - t_0}{W_d} \left(\frac{3180}{x} + 50n + 37{\cdot}6 \right) \qquad (11)$$

THE QUANTITY OF AIR THEORETICALLY REQUIRED FOR COMBUSTION AND THE EXCESS NECESSARY

The volume of air theoretically required for the complete combustion of 1 cu. metre of natural gas is given by the equation

$$P_{th} = \frac{2\eta + (4m + n)\,\zeta - 4\theta}{84} \qquad (12)$$

While the excess necessary is given by

$$P_a = \frac{100}{79} \cdot \frac{aV_1 - a}{100}$$

Expressed as a ratio of the quantity actually used and the quantity required for theoretical combustion, it becomes

$$V = \frac{84\,(aV_1 - a)}{158\eta + (316n + 79m)\,\zeta - 316\theta} \cdot$$

RÉSUMÉ.

Si l'on utilise le gaz souterrain comme combustible pour les chaudières à vapeur, les pertes de chaleur diffèrent de celles qui se présentent d'habitude dans le cas de chauffage au charbon. Ce sont surtout les pertes par les gaz non-brûlés et les pertes par la cheminée qui doivent être considerées spécialement dans ce cas.

L'auteur examine le processus de la combustion du gaz en se basant sur les indices n et m dans la formule C_nH_m des hydrocarbures qui constituent le gaz. Il donne les formules pour le calcul des pertes mentionnées plus haut, de la puissance calorifique des produits non-brûlés, enfin de la quantité d'air nécessaire à la combustion, en fonction du pourcentage des divers constituants du gaz et des produits de combustion.

POLISH COAL AS FUEL FOR LOCOMOTIVES

POLISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

S. KRUSZEWSKI

Paper No. J10

CONTENTS

General Characteristics

The Polish coalfields, although geologically constituting one whole, are divided into three basins in the Upper Silesian, Cracow (including Teshen) and Dąbrowa areas.

So far as the resources of coal are concerned, Poland occupies the third place in Europe (after Great Britain and Germany) possessing, at a depth of 1,000 metres, and at a minimum thickness of coal seams of 0·5 metres, 14 milliard tons of actual resources, 29 milliard tons of seams probably workable, and 19 milliard tons of coal which might possibly be worked, or a total of 62 milliard tons.

The seams of coal are divided into three groups: (1) synclinal, (2) anticlinal and (3) border group. The most productive of these is the anticlinal group, which is composed of thicker seams than the other groups, and which lies approximately along a line drawn through Królewska Huta and Sosnowiec; it constitutes, together with the somewhat more Northern parallel basin of Bytom-Maczki, a district which, although comprising only up to 12 per cent. of the total area of the Polish coalfields, has concentrated within itself up to 73 per cent. of the total output of coal in the Upper Silesian and Dąbrowa area; this district thus constitutes a deciding factor in the coal industry of Poland, as a source of export abroad and of home consumption.

All of the three groups of seams contain coal of a varying calorific value. The highest value is obtained in the west, decreasing as one

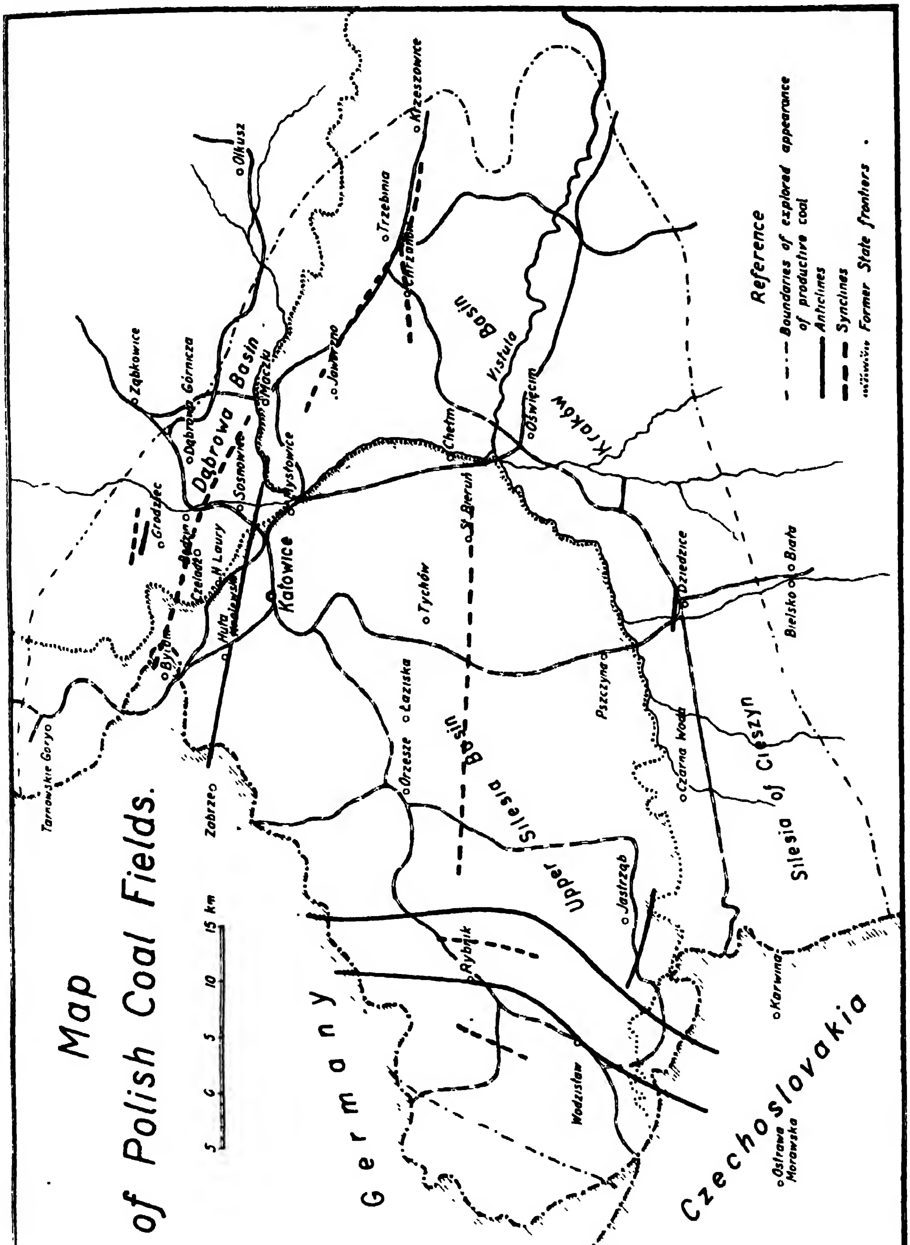


Fig. 1.

travels East. In the anticlinal group, the initial value of 7,400 calories to the west of Królewska Huta gradually decreases down to

7,000 in the Uppe. Silesian basin and to 6,500 and 6,200 in the Dąbrowa basin; in the border group, from 6,700 calories in the west (Rybnik) down to 6,400 in the east (Dąbrowa basin); and, finally, in the synclinal group from 7,000 calories in the west. down to 5,000 calories in the Cracow basin. Therefore, dependent upon the seam under exploitation in the respective area, each colliery has a more or less stabilised quality of coal.

Although o varying calorific value, all qualities of coal of the Polish coalfields are long-flaming in character, containing from 30 per cent. to 35 per cent. of volatile matter. The chemical composition is not uniform; in the west the coal shows a higher percentage of hydrogen, which decreases in an easterly direction, whereas the percentage of oxygen increases. In the same direction the caking-power of the coal decreases; to the south-west of Katowice, on the frontiers of Upper Silesia, caking coal is found which, on combustion, forms a fused porous mass; the output of this coal at present amounts to 6 7 per cent. of the total output of coal from the entire Polish coalfields. To the east and north-east, the caking-power of the coal decreases and entirely disappears in the Dąbrowa and Cracow coal. The value of the coal for gas making decreases as we progress towards the east and north-east, and the coal of the Dąbrowa and Cracow districts cannot be used for this purpose.

The Polish coalfields thus contain all qualities of coal with the exception of highly-caking coals, lean anthracite and anthracite. From a utility point of view, this coal is suitable for coke ovens, gas works and industrial furnaces, though for the greater part it constitutes fuel coal which ignites and burns easily, even in thick layers on small grates.

So far as hardness is concerned, the Upper Silesian and Dąbrowa coal ranks among the hardest, which has a decisive influence on the mining of the coal and on the method of sizing it. The Cracow coal is less hard, crumbles up easily and is more interspersed by iron-pyrites, contains more sulphur and is unsuitable for long-distance transport.

The ash content is variable, though generally not to any considerable extent. The clinker produced from the coal contains insignificant, though varying quantities of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3), which make the clinker easily fusible, tending to fill the openings in the grate. The Dąbrowa and Cracow coal are practically free from these components, being fragile and crumbling, whereas Upper Silesian coal yields a somewhat harder clinker, more difficult to remove.

Explosions of gases occur very rarely; the mines are even lit by naked-flame carbide lamps.[1]

The temperature under working conditions in the collieries is favourable, as it approximates to 15–20°C. A temperature of 28°C., which might impede work, is rarely to be met with.

The screening of coal in Poland provides from five to nine sizes which, however, have not yet been standardised throughout the coal-fields; large coal, cobbles, mixed nuts, pea coal, small coal, mixed screenings and unsorted coal (run-of-mine). From these, cobbles are in two sizes I. and II.; nuts—Ia., Ib., II. and III.; duff—I., II., III. and IV. Certain grades (nuts and dross) are improved by washing.

The characteristics of the screening of coal in the Upper Silesian and Dąbrowa coal districts have been demonstrated by Prof. Czeczott, of the Cracow Mining Academy (Fig. 2), in the form of a curve, marking off on the axis of abcissæ the consecutive diameters of the screen meshes (from 0 mm. on) and on the axis of ordinates the percentage of the grade which does not pass through the screen mesh of the corresponding diameter.[2]

The sales of coal from the collieries in 1927, in individual sizes, were as follows :—

	PERCENTAGE												Sales in thousands of tons
	Large[1]	Cobbles[2]		Nuts[3]			Peas[4]	Slack		Duff[5]	Run-of-mine	Waste	
		I	II	I.	II.	III.		0–70	0–35				
Upper Silesian Coal—													
For home consumption	14	13	3	6	3	5	8	5	5	32	5	1	15,369
For export	25	19	5	15	5	6	9	8	1	4	3	-	9,680
Dąbrowa Coal													
For home consumption	28	23	7	8	6	4	6	2	—	15	1	—	4,778
For export	22	31	25	11	5	2	2		-	1	1		1,891
Cracow Coal													
For home consumption	24	18	13	8	9	10	--		-	13	5		2,048
For export	12	28	28	8	12	8		1	1	2	-	---	7
Total													
For home consumption	18	16	5	7	4	5	7	4	3	26	4	1	22,195
For export	25	20	8	15	5	5	8	7	1	3	3		11,578

[1] 120 mm [2] 50–120 mm., [3] 15–50 mm., [4] 10–15 mm.; [5] 0–10 mm.

The size of Polish coal bears a direct relation to the calorific value. Large coal and No. 1 lump coal are often entirely free from useless impurities, whereas the smaller grades progressively contain larger proportions of impurities, the largest being found in duff.

[1]Karl Borchardt and Dr. Kate Bonikowsky—"Handbuch der Kohlenwirtschaft" 1926.

[2]Journal "Przegląd Techniczny," Vol. 65, 1927, page 500.

The greatest resistance to atmospheric influence is shown by the larger grades of coal, where per unit of weight there is the smallest outside area, subject to atmospheric influence, while the smaller grades of coal more readily absorb moisture. Upper Silesian and Dąbrowa coals (mostly synclinal) are less resistant and decompose more speedily.

Researches carried out in connection with the larger sizes of Dąbrowa coal at open-air railway dumps have proved its resistance; the researches were carried out in duplicate with dumps deposited in spring and autumn; the relative weight of the coal from the autumn dump decreased in the course of a year by almost 5 per cent., whereas

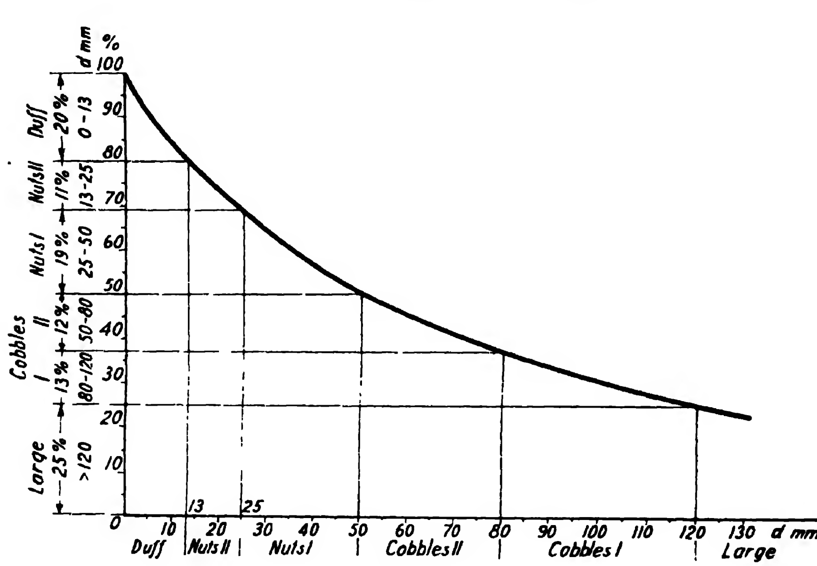


Fig. 2.

that from the spring dumps decreased by only up to 3 per cent., which was due to drying; the decomposition of the coal, determined by the degree of fragility, was more marked in the autumn dumps (fragibility became greater by 25 per cent. after one year's storage) than in the spring dumps (18 per cent. after one year). The calorific value of the autumn coal decreased in one year by almost 3 per cent., whereas the spring coal, as a result of loss of hygroscopic water, remained practically unchanged.

From various kinds of coal, mostly from Upper Silesian duff or from waste duff mixed with peas, in some instances with caking coal, six briquette factories manufactured in the course of 1925 384,000 tons of briquettes, of which approximately 20 per cent. was exported abroad.

UTILISATION OF COAL BY POLISH RAILWAYS

The railways naturally cover their requirements from the abundant home coal market described above.

The requirements of the railways in thousands of tons were :—

Coal basin.	1924	1925	1926	1927
Upper Silesian ...	1,117	1,205	1,185	2,058
Dąbrowa	1,362	1,321	1,160	1,168
Cracow	646	726	792	1,062
Total... ...	3,125	3,252	3,137	4,288

Thus, the requirements in 1927 represented one-fifth of the total sales of the home collieries, or, by basins : 13 per cent. of the Upper Silesian, 24 per cent. of the Dąbrowa, and 50 per cent. of the Cracow basins, which shows that, in selecting coal, the railways were not guided particularly by the best properties of the coal, but by cheapness. Mostly boiler and fuel coals were being purchased, whereas industrial coal was purchased for workshop use (forge coal).

As far as sizes and basins are concerned, the percentage rate of consumption of coal by the railways in the course of 1927 is represented in the following table :—

Basin.	Large	Cobbles (Lump)		Nuts.			Peas	Slack.		Duff	Run-of-mine.	Waste.	Sales in thousands tons.
		I.	II	I.	II.	III.		0 70	0·35				
Upper Silesian	42	10	1	11	9	6	2	1	—	—	17	1	2,058
Dąbrowa	59	14	9	8	5	3	—	—	—	—	2	—	1,168
Cracow ..	29	11	18	13	14	17	—	—	—	—	8	—	1,062
Total	44	11	8	11	9	5	1	—	—	—	11	—	4,288

As fuel for stationary boilers, smaller grades of coal are used.

The supplies of coal for the use of railways are on the basis of contracts concluded with the individual colliery concerns, in accordance with standard specifications, which on the one side take into consideration the properties of the coal produced and the screening methods of the collieries, and on the other—the possibility of the most effective utilisation of the coal for locomotive and stationary boilers.

The guiding characteristics of the quality of coal are provided by the class under which each respective colliery and grade have been classified. The coal is obtained from all the largest collieries of each coal basin.

In order to obtain a thorough appreciation of the qualities of the available kinds of coals, over two thousand analyses have been

carried out between May 1924, and the end of 1927, at the laboratories of the National Geological Institute in Warsaw, and of the Cracow Mining Academy; and approximately 3,800 technical acceptance tests were carried out at the collieries. Considering that the major portion of coal intended for the railways is consumed by locomotives, parallel practical tests on locomotives under normal working conditions were carried out, simultaneously with laboratory experiments.

On the basis of the above researches, and after having jointly agreed (with the representatives of the colliery concerns) upon the "All-Polish Coal Convention," the collieries throughout the Polish coalfields were divided—not territorially, by the three individual basins but in accordance with the value of the larger grades of coal produced (large lump and nuts) into four categories, the various qualities of coal from the individual basins being allocated to various categories.

The definition of the quality of coal has been based on its gross calorific value, without having made corrections for quantity of ash and for percentage of water.

The following numerical characteristics for the respective categories have been fixed as normal :—

Categories of coal.	Heating value in calories	Percentage of ash
I.	7,000	5·0
II.	6,300	6·0
III.	6,000	7·5
IV.	5,400	10·0

These figures are subject to certain tolerances as to ash content and calorific value; smaller limits for coal of the higher categories, wider limits for coal of the lowest category. In view of the fact that there are cases where analysis shows more ash than is permissible, but simultaneously also a higher calorific value, the final definition of the quality of coal is reckoned as the equivalent per 1 per cent. of ashes: for coal of category I.–100 calories, of categories II. and III.–75 calories and of category IV–60 calories; such calculation, however, is of rather a guiding nature only. Actual figures for collieries included in one category show very considerable fluctuations.

For statistical calculations of the railways, coal of No. II. category (good Dąbrowa coal) has, for practical purposes, been taken

as the standard, and the following ratios have been fixed for all four categories in relation to category II. :—

I.	II.	III.	IV.
1·10	1·00	0·95	0·85

The purchase prices at colliery, however, show a somewhat different ratio, namely (in round figures):—

I.	II.	III.	IV.
1·060	1·000	0·985	0·970

The computation of both ratios shows that operation cost is the most advantageous in the case of No. I. category coal, whereas it is the least advantageous in the case of coal of the lowest category, *i.e.*, of Cracow coal.

Referring to the technical value of the various grades it must be stated that this value decreases with decrease in the size of coal. On scheduling the grades of coal of each category in accordance with quality and simultaneously comparing these with the corresponding present ratio of price of each grade, the following table is obtained :—

GRADES	CATEGORY.							
	I.		II.		III.		IV.	
	Value	Price.	Value.	Price.	Value	Price.	Value.	Price.
Large and cobbles	1·10	1·060	1·00	1·000	0·95	0·985	0·85	0·97
Nuts	1·00	0·900	0·90	0·835	0·85	0·825	0·75	0·82
Run-of-mine	1·00	0·820	0·90	0·775	0·85	0·765	0·75	0·65
Briquettes .	1·00	1·060	—	—	—	—	—	—

It is apparent from the above schedule that smaller grade and run-of-mine coal is economical when used as fuel for locomotives, whereas the use of briquettes is too expensive.

Duff is not used at all for locomotive fuel, as it does not cake, and thus falls through to the ash pan. Only small Upper Silesian coal (a mixture of larger peas with duff) is used as an addition to larger size dry coal, owing to its high caking properties.

The calculation of prices at colliery, however, does not in itself constitute an accurate calculation; in view of the situation of the coalfields on the south-western border of the country, the coal for the use of railways has to be transported over long distances and, in order that the price per calorie of coal at the point of consumption should be as reasonable as possible, a principle is observed of supplying the districts nearest to the coalfields with inferior qualities of coal and those farthest with the higher qualities, as far as calorific value is concerned, as the latter resist transport to a greater extent.

The characteristics of coal of the individual categories may well be supplemented by a chemical analysis of the coal from individual fields in each category. The table reproduced below schedules the minimum and maximum percentage of components: carbon, hydrogen, nitrogen and sulphur.

Percentage content of components	Category I. Upper Silesian.	Category II. Upper Silesian.	Category II. Dąbrowa.
Carbon - C ..	78·3 — 61·0	69·7 — 63·8	67·5 — 58·9
Hydrogen - H ...	5·19 — 4·00	5·15 — 4·20	4·85 — 4·00
Nitrogen - N ..	1·35 — 0·90	1·15 — 0·90	1·40 — 0·80
Sulphur - S ...	1·90 — 0·65	1·55 — 0 85	1·80 — 0·80

Percentage content of components.	Category III. Upper Silesian	Category III. Dąbrowa.	Category IV. Upper Silesian	Category IV. Dąbrowa.	Category IV. Cracow.
Carbon - C	69·5 –57·5	64·1 –60·5	67·7 –62·0	61·3 –55·2	70·0 –52·5
Hydrogen - H	5·0 – 3 65	4 33– 3·90	4 5 – 4·0	4·22 3·81	5·2 – 3·3
Nitrogen - N	1·25 · 0·87	0 90– 0·75	1·1 – 0·8	0·90– 0 70	1·45– 0·8
Sulphur - S	1·65– 1·10	2·22– 1·47	2·75 1·35	2 38– 1·00	2·0 – 0·5

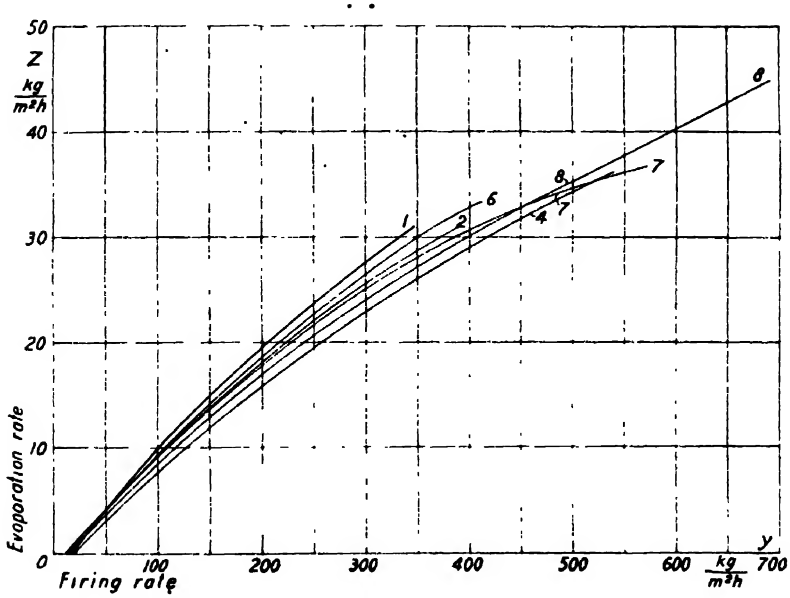
Taking into consideration the above characteristic features of coal from individual basins, the railways submit to the collieries certain acceptance specifications for coal as fuel for locomotive boilers, with a view to its most satisfactory adaptation to the technical working conditions of the different types of locomotives, and the economic utilisation of the individual properties of the coal. Among others, the following stipulations are laid down, making due allowance for the class of the colliery: (1) that the coal should be fresh, *i.e.*, that it should not have been produced more than two months prior to despatch; coal which has been lying at dumps for a longer time is subjected to special acceptance; (2) the coal should be mechancially screened in accordance with the sizes required for the various grades.

Special technical inspectors carry out systematic acceptance by taking samples of the coal for laboratory test, in accordance with special instructions; they also ascertain from what seams the coal has been obtained. Coal briquettes, for which the Railways are the main home consumer, must comply with special railway conditions as to shape, size, weight and compression

The properties of the individual grades of coal from the various coalfields are also taken into consideration by the railways for storage purposes. For this purpose, the larger grades of Upper Silesian and Dąbrowa coal and briquettes are mainly selected and,

as a rule, such supplies are renewed after a year's storage. Coal storekeepers are required to dump the coal into heaps by two grade groups for each category, provided the space available does not allow for more detailed grading, as, for instance, by so-called calculation factors, the coal then being issued in accordance with previously prepared instructions as to its destination.

In the above manner, the coal problem is being solved in both its technical and its economic aspects, taking into consideration the prevailing conditions of the output of coal in the Polish collieries and the working conditions of the Polish railways.



1 Kadievka mine | 4 Grodziec mine | 7 Newcastle
2 Scherbinovka ,, | 6 Yorkshire | 8 Saturn mine

Fig. 3.

The question, however, became of importance as to the merits of Polish coal for locomotive fuel as compared with foreign coal. A fragment of a substantiated reply was provided by the comparative tests carried out by the writer in 1913 with certain types of coal,[3] *i.e.*, the aforesaid standard coals, namely British, Polish from Dąbrowa basin and Russian coal, as fuel for locomotive boilers.

The following qualities of coal were used for these tests :—

(1) *British* : Yorkshire and Newcastle coal, without discrimination of collieries.

[3]Stanisław Kruszewski: Badania porównawcze węgli. See Journal "Przegląd Górniczo-Hutniczy," 1914.

(*a*) *Yorkshire Coal* is large, with a considerable percentage of nuts; is hard, easy to handle, possesses a semi-dull surface, is sometimes interspersed by partings and ignites easily, though when charged heavily it yields a black smoke with a smell of pitch. In the locomotive fire-box, after a few journeys, the heads of stay bolts of the fire-box crown showed formations of large stalactites composed of a fragile deposit, whereas on the flanges of smoke tubes scale was deposited which gradually choked the openings. With heavy firing, the coal yields much clinker and fills the grate openings. A firing rate of more than 400 Kg. per sq. metre per hour cannot be maintained.

(*b*) *Newcastle Coal*, of a lower calorific value than Yorkshire coal, has a lesser tendency to smoke and a greater tendency to sparking; on being wetted out it cakes to a greater degree· its combustion is easier than that of Yorkshire coal. With a firing rate of 500 Kg. per sq. metre per hour, further forcing becomes useless.

(2) *Russian, Donetz Coal* (South) from the Kadjewka and Scherbinowka mines :

(*a*) *Kadjewka caking coal*, run-of-mine, cakes on the grate, forming moderately hard coke, and may be burned on a grate with 18 mm. spacing. It burns with a short, white and limp flame. Owing to the considerable percentage of SiO_2 and Al_2O_3 in the ash, it covers the grate with fusible clinker, which is produced in greater quantity, the greater the load on the grate; a firing rate of 400 Kg. per sq. metre per hour is the limit, after which more intense firing becomes useless and the powerful draught throws out fragments of coke.

(*b*) *Scherbinowka caking coal*, run-of-mine, yields a slightly stronger coke than the Kadjewka coal and a somewhat longer, though lean and white flame.

(3) *Polish Coal* from the Dąbrowa basin, from the "Saturn" and "Grodziec" collieries—large, non-caking and yielding little clinker; this coal is long-flaming, dry, and ignites very easily. It is sufficient on lighting the fire to stoke a few shovels of this coal on to the grate. Under forced draught, the air-blast splits off particles of the coal which ignite and burn in sparking fragments; by firing with larger lumps and a thicker layer of coal, a firing rate of 700 Kg. per sq. metre per hour was reached, chiefly due to easy inflammability, smaller percentage of ash and the property of slight clogging of the grate (smaller percentage of SiO_2 and Al_2O_3). This feature of easy combustion of the Dąbrowa coal is exceedingly valuable in the management of locomotive boilers: due to the ease of forcing, it renders the boiler elastic in the event of the necessity occurring

for intensified working of the locomotive. Such occurrences are frequent as, for instance, if on a certain sector of the line there are not excessively long but steep gradients which are decisive in the selection of the size of boiler and typical constitution of the trains on this particular line, or where delay must be equalised by faster running which, particularly in the case of passenger trains, is of great importance.

The comparative analyses of the above qualities of coal are given in the following table :—

Chemical composition.	English		Russian.		Polish.	
	Yorkshire.	Newcastle.	Kadjewka mine.	Schcherbinowka mine.	"Grodziec mine.	"Saturn" mine.
Water per cent	3·46	6·60	2·22	6·00	13·06	7·53
Ash ,,	8·12	7·79	6·85	6·76	4·45	5·36
Carbon C ,,	73·64	71·52	79·49	74·07	65·88	68·67
Hydrogen H ,,	4·63	4·60	4·78	4·35	3·76	4·25
Sulphur S ,,	1·77	1·34	1·01	1·48	0·94	0·66
Nitrogen N ,,	1·15	1·16	1·12	0·96	0·75	0·90
Oxygen O ,,	7·23	6·99	4·53	6·38	11·16	12·63
Characteristics:						
Water .. per cent.	3·46	6·60	2·22	6·00	13·06	7·53
Ash .. ,,	8·12	7·79	6·85	6·76	4·45	5·36
Fixed carbon ,,	57·18	56·25	67·36	64·25	55·37	54·03
Volatile matter ,,	31·24	29·36	23·57	22·99	27·12	33·08
Gross heating value, calories	7,388	7,079	7,860	7,328	6,258	6,609
Net heating value, calories.	7,117		7,589	7,057	5,977	6,334

The comparative test runs were based on the principle that each fuel should be given the most advantageous means of combustion in accordance with its physical and chemical properties. Ten test runs, under identical conditions, were carried out with each kind of fuel, a typical freight engine being selected for this purpose, namely, the standard locomotive 0-8-0, with a ratio of grate area to heating surface of 1 : 75. In the course of the runs, all the usual records were made to permit the preparation of a thermal balance chart. As a result of each run, the firing rate and the rate of evaporation in Kg. per sq. metre per hour were determined.

The firing rate (x) marked off on the axis of abscissæ and the evaporation per unit of heating surface (z) on the axis of ordinates, produced a curve for each of the qualities of coal, a complete set of which is shown in Fig. 3.

This demonstrates the greater flexibility of the grate when using Polish (Dąbrowa) coal, than when using others, the curves for which, initially higher than the curves for the Polish coal, intersect the latter curves and fall below under higher loads.

Coal from the Silesian basin, owing to its higher calorific value with an identical percentage of volatile matter, produces still

better technical results. The Cracow coal, also long-flaming, though lower in calorific value, and less pure, is usually applied for less responsible work.

RÉSUMÉ

L'auteur caractérise les qualités de la houille polonaise et son aptitude à l'utilisation pour le chauffage des locomotives; il envisage la classification ainsi que la façon dont les Chemins de fer procèdent à l'achat de la houille. Ensuite il cite des résultats comparatifs d'expériences effectuées sur les locomotives avec de la houille polonaise, anglaise et russe.

METHODS EMPLOYED BY THE POLISH RAILWAYS IN ORDER TO PROMOTE FUEL ECONOMY

POLISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

STANISLAW FELSZ

*Paper No. J*12

CONTENTS

Engine Staff

The realisation of the highest possible efficiency of a boiler working at any particular firing rate depends, as is commonly known, on the proper combustion of volatile matter, on the supply of the proper excess of air to the furnace, on the proper handling of feed apparatus with pre-heated water and other factors.

If the attainment of this elementary economy depends on the engine fireman, whose mental level does not allow him to understand the principles of combustion, skilled stoking is based on weak foundations, in spite of inducements in the shape of premiums.

For this reason the permanent firing service on the Polish State Railways is carried out by assistant engine drivers. These men are selected from among metallurgical workmen, with an educational status of at least a secondary school.

After having completed the locomotive apprenticeship and an additional finishing course, the candidate is appointed to the permanent staff as assistant engine driver, then, after a certain time and after having passed an additional examination, he becomes auxiliary engine driver and, finally, after many years of service on various types of locomotives he becomes a qualified driver.

This system provides a staff which is able to understand the fundamental principles of combustion and of general thermal economy as applied to locomotives, and which simultaneously has had the benefit of thorough all-round experience.

ENGINE CREW

The average working engine is able to perform 1·5-2 times more work than a single engine crew working 200-240 hours per month. In order, therefore, to secure the utmost economy in the engine and crew, it would in many instances be found necessary to provide an alternating service: for n train engines—$(n+x)$ crews, where x may vary from $0{\cdot}5n$ to n.

However, the system of non-permanent alternating crews is accompanied by all the bad effects of communal economics, depreciation of engines, more costly repairs, increased interruptions in service, increased percentage of engines under repair and increased consumption of coal. *In view of this fact, the granting of premiums for economy in coal gives very significant results, if based on a permanent crew* (*single, double or triple*).

In principle, on the Polish State railways, each working locomotive is served by two permanent crews to whom the option is given of mutual selection. In separate turns, where double crews cannot be properly utilised, as for instance on some of the express trains, a system of single crews is relied upon at the expense of an increase in the number of engines by 10-30 per cent. On 24-hour work, the shunting engines are usually served by three permanent crews.

PREMIUMS FOR ECONOMY OF COAL

In the case of a 1-3 crew-system working on an engine, the coal is estimated on a common basis for all crews serving the engine. The premiums for coal saved are estimated per engine and distributed among the crews in proportion to the number of engine-kilometres of service of each.

The rates of train premiums are double: for the engine itself—per engine-kilometre, and for loads carried—per 1,000 ton-kilometres gross. The rate for the engine itself consists not only of coal consumed during the run of the engine, but also of that wasted at stops and when running with closed throttle valve, calculated per engine-kilometre.

The rate per engine itself is fixed accurately on the *estimated consumption, whereas the train rates for load carried* (per 1,000 ton-kilometres) *increase in proportion to the estimated consumption by the*

amount of the entire reserve of premium. The object of this protectional policy in fixing these rates is to encourage the crews to welcome a possible increase of the loads carried.

As a result, the engine crews gladly carry maximum complements and even excessive ones, as this automatically yields a benefit to them through the increased premiums. Simultaneously, the total consumption of coal per 1,000 ton-kilometres decreases, in view of the fact that the consumption of the engine itself, which amounts to from one-half to one-quarter of the total quantity of coal consumed by the train, is divided by the greater effective load of the trucks.

Economic Unit of Consumption of Coal on Locomotives

This policy of allowing premiums is to a great extent dependent on the unit adopted for the calculation of the consumption of coal on locomotives, as under such premium policy the consumption of coal per load of the train decreases, whereas it increases per engine-kilometre.

So far, in the budgets and statements of the railways the calculation of the consumption of coal is effected per engine-kilometre. This method is not accurate. It will show that apparently the most economic operating system of railways will be that which is based on small train units, large numbers of runs without loads, considerable shunting, reserves and every auxiliary work, which is cheaper as far as the consumption of coal per engine-kilometre is concerned, whereas there is little transport work done which actually is more expensive per engine-kilometre.

The budget standard of fuel consumption reckoned per engine-kilometre militates against the entire effort for transport economy.

The most correct calculation would be to reckon the coal consumption per 1,000 ton-kilometres of load carried. In view of the difficulties connected with such a method, it would be necessary to rely on an estimate of coal consumption per 1,000 ton-kilometres gross, *i.e.*, based on the load of the train.

As a matter of course, on hilly and flat lines and also for various types of trains, the consumption of coal per 1,000 ton-kilometres will differ by considerably more than if reckoned per engine-kilometre.

It is, however, not the method of calculation, giving the more even consumption of coal, which is the correct one, but that which gives the correct economic impulse to the operating service and to transport economy.

For this reason, the Polish State Railways have from 1927 adopted both the general and premium system of budgeting in kilograms of standard coal per 1,000 ton-kilometres gross, instead of the former system based on the engine-kilometre. By this system, all coal consumed for driving and auxiliary purposes is counted.

The conversion of the coal consumption from one system to the other is easy, provided the average estimated load per engine-kilometre is given $q = \frac{\Sigma Q}{\Sigma P}$ (where "ΣQ" is ton-kilometres gross carried, and "ΣP" is the number of estimated engine-kilometres).

Then $r_p = 0{\cdot}001\ r_q q$ (where r_p is the consumption of coal per engine-kilometre and r_q the consumption per 1,000 ton-kilometres gross).

The number of estimated engine-kilometres. depends on the kilometric ratios adopted per hour of auxiliary work, *i.e.*, shunting and reserve.

On the Polish State Railways each hour of shunting is reckoned as 5 engine-kilometres (reserves as 2 Km.)

On this subject there is no international convention, and, for instance, on certain railways the equivalent per shunting hour is 10 Km.

Provided we do not consider the usually insignificant number of idle periods and runs without load, it is easy to establish the following formula for the estimated load per engine-kilometre.

$$q = \frac{Q}{1 + p\,{}^{\Sigma H}/_{\Sigma Z}}$$

where Q is the weight of an average train,

p the agreed equivalent factor for shunting (5-10 Km.)

${}^{\Sigma H}/_{\Sigma Z}$ the number of shunting hours per train-kilometre.

If, for instance, at ${}^{\Sigma H}/_{\Sigma Z} = 0{\cdot}06$ hour and at the agreed factor equivalence $p = 5$ Km., the consumption of coal per engine-kilometre $r_p = 25$ Kg., the consumption will, under identical economic factors, but at a factor of equivalence of $p = 10$ Km., decline to 20 Kg. per engine-kilometre. It is also evident from the formula for r_p how the consumption of coal per engine-kilometre declines under unsuitable transport conditions, if the load of trains (Q) is reduced and the time for auxiliary work per train-kilometre (${}^{\Sigma H}/_{\Sigma Z}$) is increased.

The consumption of coal estimated on the weight does not depend on the agreed value p, and increases in proportion to the deterioration of general transport conditions. The question of the calorific value of the coal also remains open. The standard coal approved by

the Polish State Railways is average large Dąbrowa coal or lump, of a net heating value of 6,300 calories per Kg., and hereafter only such coal is referred to.

General Economic Means for the Reduction of Coal Consumption

The tendency towards reduction of coal consumption per load carried combines harmoniously with the general means for reducing the costs of transport. One of these means, and one generally approved of, *is the replacement of lighter type engines by heavier ones*, which increases the load of the average train, but by this means the consumption per unit of load carried decreases.

In a similar manner, *the granting of premiums to the operating staff and engine crews for increased efficiency of shunting work* affects the consumption of coal. The premiums are payable on the increased number of trucks shunted per hour above a fixed limit,

In spite of the increase of engine work under such premiums, the shunting hour is always reckoned in a constant manner, so that the coal consumption per engine-kilometre increases. The general number of engine-hours of shunting work, however, considerably decreases. For instance, previously to the adoption of the premiums by the Polish State Railways, auxiliary work, *i.e.*, shunting (5 Km. per hour) together with reserves (2 Km.), stand-byes (1 Km.) and no-load runs amounted to from 32-30 per cent. of the total number of engine-kilometres. After the adoption of these premiums in the middle of 1925, this percentage decreased in 1927 to 23 per cent. This naturally lessened the consumption of coal burned in the course of shunting relatively to the total coal consumption and to the unit of loads carried.

We must further reckon with such factors as reduce the considerable proportion of waste combustion of fuel in the total coal consumption. Coal burned as waste burdens in an equal manner each engine-kilometre or each 1,000 ton-kilometre gross. The greater the daily work of the engine, the smaller the waste combustion per unit of work.

Thus, for instance, a freight engine with a 4·2 sq. metre grate running on a section with a 180-Km. turning terminus, covers a distance of 180 Km. per day and performs 225,000 ton-kilometres of haulage. At a waste combustion of coal at the rate of 720 Kg. per twenty-four hours, the waste rate per engine-kilometre amounts

to $\frac{720}{180}=4$ Kg., or per 1,000 ton-kilometres $\frac{720}{225}=3{\cdot}2$ Kg. This amounts to approximately 12 per cent. of the total quantity of coal consumed by the engine.

A similar type of engine running on a section with a smaller turning terminus (30 Km.) has a waste consumption of coal of 840 Kg., while covering a distance of three runs per day, *i.e.*, of only approximately 90 Km. and having a performance of 108,000 ton-kilometres. In this instance, the percentage of waste combustion of coal per engine-kilometre increases to $\frac{840}{90}=9{\cdot}3$ Kg., or per 1,000 ton-kilometres to $\frac{840}{108}$ $=7{\cdot}8$ Kg., which amounts to as much as 20 per cent. of the total consumption of coal under above conditions.

Thus, in order to diminish the rate of waste per unit of work, *efforts should be made to increase the run of the engine by possibly increasing the distance to the turning terminus and by granting premiums to the executive staff for shortening the time of superfluous stops of freight trains at stations and outside stations.*

The increase in the distance to the turning terminus must, however, be limited to the standard continuance of working hours of each engine crew, in view of the fact that the increase of the distance to the turning terminus to several hundreds and thousands of kilometres is only practicable under a system of alternating crews which, for other reasons, produces detrimental effects under conditions prevailing in this country.

Control and Statistics of Coal Consumption

The control over the calorific value of coal purchased, over the grades of coal supplied, over their selection and distribution to the individual coal dumps, over the utilisation of refuse, etc., are matters of a general character and sufficiently prevalent everywhere. *In this connection it is necessary to emphasise the advantage of control by the engine drivers of the quantity and quality of coal supplied to their engines.*

For this purpose, the fitting to the ordinary winches and elevators of robust and accurate dynamometers of the special Zakiewicz design has been found very useful.

The application of all sorts of technical coal-saving devices is effected in such a manner that, after having tried these on the engine and having obtained satisfactory results, experiments are being conducted in a whole series of engines of a similar type, one group being fitted with such devices and the other not. Both groups

must work in a common train service, *i.e.*, under analogous conditions as far as the average quality of coal, atmospheric and territorial conditions, working resistance, waste combustion, grate load, etc., are concerned.

For greater accuracy in comparison, each group consists of at least several engines for the purpose of equalising individual differences in the efficiency of stoking, in the wear of the engine and locomotive and in the condition of the locomotives. The comparative schedules of monthly consumption of standard coal of each group calculated, for instance, per 1,000 ton-kilometres gross at a more or less equal average load per engine-kilometre provide in the engine service an actual proof of profits and losses obtained with each individual device.

Only such complete comparative statistics of coal consumption of individual groups under prevailing working conditions properly qualify such devices as far as their utility is concerned, and determine the terms of the economy effected thereby. In this manner, for instance, a smaller consumption of coal has been obtained with an injector for exhaust steam as compared with a pump and pre-heater, in addition to the fact that the latter also involves higher cost of maintenance and repair.

The annual schedules of the consumption of coal by the various classes of engines indicate the progress in economy under individual working conditions. By this means, the results as to the use of suitable types of engines for individual classes of work may also be obtained. Thus, for instance, for shunting work at a station, where heavy train units have to be combined, the consumption of coal for tank locomotives amounted in 1925 to 118 Kg. per hour; the replacement of this light type by heavy train-type engines with saturated steam, but with larger capacity cylinders and larger driving weight, in 1926 resulted in a reduction in the consumption of coal to 98 Kg. per hour. The further replacement of this twin type engine by a similar type of compound engine resulted in 1927 in a reduction in the consumption to 87 Kg. per hour, in spite of the fact that in both these years the premiums for intensified shunting work had a considerable influence and the efficiency of work considerably increased without involving an increase in the number of shunting engines.

RESULTS ACHIEVED

The results of the application of the above means of organisation of advanced engineering methods, and the granting of premiums,

are most striking from an example extracted from the statistics of one of the District Departments of the Polish State Railways, which handles approximately 30 per cent. of all traffic. The lines in this district have flat gradients, with a maximum of 8 degrees. The daily traffic amounts to thirty-two trains per kilometre.

In the course of the first post-war year (for Poland), 1921, the consumption of coal amounted to 100 Kg. per 1,000 ton-kilometres. At an average load per engine-kilometre of 345 tons, the consumption amounted to 34·5 Kg. per engine-kilometre.

The coal premiums based on the Flamm system which were being applied in 1922 and 1923, and the premiums based on the engine-kilometre which were being applied in 1924, caused a reduction in the coal consumption in 1924 down to 75 Kg. per 1,000 ton-kilometre. The consumption per engine-kilometre declined to 27·5 Kg. This is the result of improvement in the condition of the engines and of the influence of the aforesaid initial premium systems. The load per engine-kilometre increased to only 367 tons.

In 1925 protection standards of premiums were introduced; new, heavier type engines were put into service; the turning termini were increased; premiums were introduced for shunting efficiency, and other steps were taken.

As a result of these measures, the consumption of standard coal decreased in 1926 from 75 to 49·5 Kg. per 1,000 ton-kilometres, this decrease remaining practically unchanged in 1927.

The consumption per engine-kilometre, however, showed but an insignificant decrease from 27·5 to 24·5 Kg.

Such considerable decrease in the consumption of coal, reckoned on the load, is mainly due to the fact that during both years the average haulage load per engine-kilometre increased from 367 tons to over 500 tons.

A decrease, similar to above, was experienced throughout the entire system of the Polish State Railways.

A further characteristic discrepancy in the calculation of coal consumption dependent on units of calculation is provided by making a comparison with the pre-war Warsaw-Vienna Railway line, which in its entirety is now comprised within the railway district under review. The consumption of identical coal on the Warsaw-Vienna Railway line amounted to less than 20 Kg. per engine-kilometre, whereas it amounted to 68 Kg. per 1,000 ton-kilometres, in view of the fact that the average load per engine-kilometre was small—290 tons.

It must be pointed out that the average consumption of coal per

1,000 ton-kilometres in reality constitutes a mixture of a series of consumption figures in the operation of individual categories of trains, dependent on loads carried, running speed, frequency of halts, waste combustion, etc.

Thus, for instance, in long-distance passenger traffic, this consumption in the district under consideration amounts to approximately 50 Kg.; in suburban traffic— 100 Kg.; in the transit goods traffic approximately 30 Kg.; and in local traffic 60 Kg. The average consumption figure depends on the participation of each class of traffic and on the coal consumed in the course of auxiliary operations (shunting).

In the highland districts smaller train units, as a result of steeper gradients and a different participation of the individual classes of traffic, must naturally produce different, and, in general, higher figures of coal consumption.

SUMMARY

The following conclusions are deduced by summarising the above statements: that the consumption per engine-kilometre of coal of an uncertain calorific value, as shown in railway statistics, cannot be considered as an index of coal economy. For proper guidance the consumption shown should at least be amplified by the following data:

(a) by the average calorific value of the coal consumed, provided an international basis is not adopted as to the calorific value of standard coal.

(b) by the average train load (gross) per estimated engine-kilometre, this being understood as representing the result of dividing the ton-kilometres gross of load carried by the number of estimated engine-kilometres, or alternatively, in a simplified manner, the consumption of coal per 1,000 ton-kilometres gross may be given.

RÉSUMÉ

Dans le but d'obtenir une consommation rationnelle de la houille par les Chemins de Fer, il faut, d'après l'auteur, faire le choix de chauffeurs convenablement instruits et introduire des primes attribuées non seulement par kilomètre de locomotive, mais aussi par kilomètre de tonne brute, en tenant compte de la valeur calorifique de la houille. De même, il faut primer le service de manœuvre et augmenter la longeur des parcours de service des locomotives. L'auteur décrit l'influence de l'application de ces moyens sur la diminution de la consommation de houille par les Chemins de fer de l'Etat Polonais. Enfin l'auteur propose d'introduire dans les statistiques la valeur calorifique moyenne de la houille consommee, ainsi que sa dépense par 1000 tonnes-kilomètres brutes

FORMULAE FOR THE ECONOMICAL RATIO OF BLENDING COALS FOR STEAM RAISING

KOREAN GOVERNMENT RAILWAYS

T. SASE

Paper No. J13

CONTENTS

CASE OF MIXING TWO KINDS OF COAL

"Digestive" Evaporation of Mixed Coals

Let the evaporation of water at a definite temperature by the unit quantities of coals A and B, which are burned under the same boiler under definite pressure, be α and β respectively. In burning the above coals mixed, in the quantities a and b, the evaporation of water e must be as follows, while no interference between them occurs,

$$e = \alpha a + \beta b . \tag{1}$$

If a and b are mixed together to make up the unit quantity, it is given by the following equation:—

$$a + b = 1 . \tag{2}$$

So the evaporation of water by the unit quantity of the mixture of two kinds of coal is obtained by combining (1) and (2).

$$\left.\begin{aligned} a + b &= 1 \\ e &= \alpha a + \beta b \end{aligned}\right\} . \tag{3}$$

Or, eliminating a between them,

$$e = (\beta - \alpha)\, b + \alpha\ . \tag{3a}$$

In this case, as shown in Fig. 1, variation of the evaporation in the combustion of mixed coal is a straight line. So if we mix the

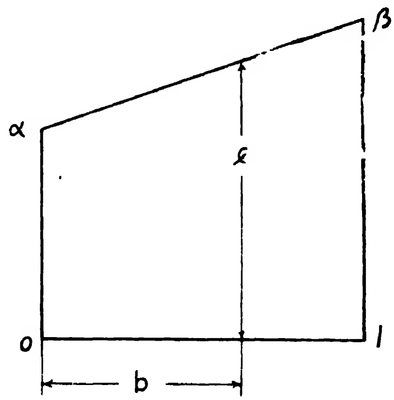


Fig. 1.

coal of greater power of evaporation in larger proportion we get greater evaporation.

But in the practice of mixed combustion of different coals we can imagine that there is some inter-relationship, such as the one kindling or dampening the other. This phenomenon I here term to be "digestive" (or "indigestive").

COEFFICIENT OF "DIGESTIVE" EVAPORATION

In the combustion of mixed coal, assume that the ability of coal A to promote (or to retard) the combustion of coal B to be m, conversely, coal B to coal A to be n, and the extra-evaporation of each case to be ϵ and ϵ', respectively. Then we can equate as follows:—

$$\epsilon = m \int_0^a \int_0^b dA \cdot dB = m\, a\, b$$

$$\epsilon' = n \int_0^b \int_0^a dB \cdot dA = n\, a\, b\ .$$

Hence, $\quad \epsilon + \epsilon' = (m + n)\, a\, b\ .$

Put $\quad \epsilon + \epsilon' = e' \quad$ and $\quad m + n = k\ .$

We then have

$$e' = k\,a\,b \tag{4}$$

where I term e' "the digestive evaporation" and k as the "coefficient of digestive evaporation" between two different kinds of coal.

Applying the equation to the mixture of two kinds of coal of the unit quantity, we have

$$\left.\begin{aligned} a + b &= 1 \\ e' &= k\,a\,b \end{aligned}\right\} \tag{5}$$

Or, eliminating a between them,

$$e' = k\,b - k\,b^2 . \tag{5a}$$

To find the extremum of e', we have the condition as follows:--

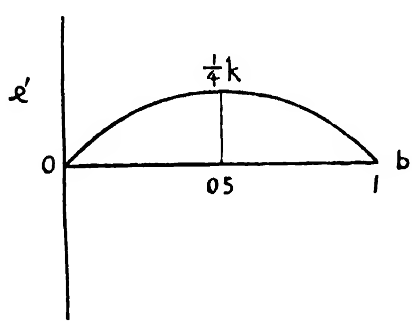
$$\frac{d\,e'}{d\,b} = o .$$

Hence,

$$a = b = \tfrac{1}{2} \tag{6}$$

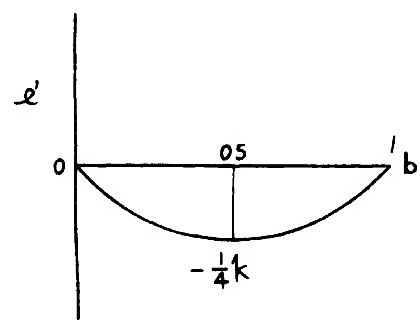
$$e' = \tfrac{1}{4}\,k . \tag{7}$$

This is illustrated in Figs. 2 and 3.



Case : k is positive.

Fig. 2.



Case k is negative

Fig. 3.

So the ratio of mixing two kinds of coal with maximum (or minimum) digestive evaporation is in each case one-half, and the value of the digestive evaporation is equal to a quarter of the coefficient of digestive evaporation.

If the actual evaporation by coal burning mixed with a certain ratio is E, we have

$$E = e + e' . \tag{8}$$

Hence,

$$\left.\begin{aligned} a + b &= 1 \\ k &= \frac{E - (\alpha\,a + \beta\,b)}{a\,b} \end{aligned}\right\} \tag{9}$$

Or, eliminating a between them,

$$k = \frac{E - \{(\beta - \alpha)\, b + \alpha\}}{b - b^2}\ . \qquad (9a)$$

Thus we can calculate the value of k by applying the results of α, β and E obtained in trials of burning the mixed coal in the ratio a and b.

Best Evaporation with Two Coals

Where the value of k depends upon the quantity of each coal, size of each, construction of boiler, object of steam supplying, draught, etc., in order to get the value of k as exactly as possible we must repeat the trials many times and average these results. After the trials, let several values of E, α, β be E_r, α_r, β_r, and the number of repeats be N''. Then the mean value k_m of the coefficient of digestive evaporation is as follows:—

$$k_m = \left(\frac{1}{N'} \sum_{r=1}^{N'} E_r - \frac{a}{N''} \sum_{r=1}^{N''} \alpha_r - \frac{b}{N'''} \sum_{r=1}^{N'''} \beta_r \right) \div a\, b\ . \qquad (10)$$

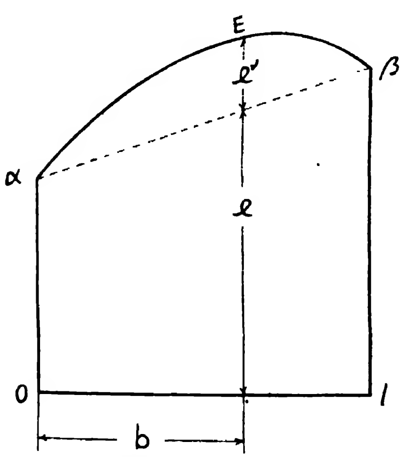
Changing equation (9), we have

$$\left.\begin{aligned} a + b &= 1 \\ E &= \alpha a + \beta b + k a b \end{aligned}\right\} . \qquad (11)$$

Or, from (9a),

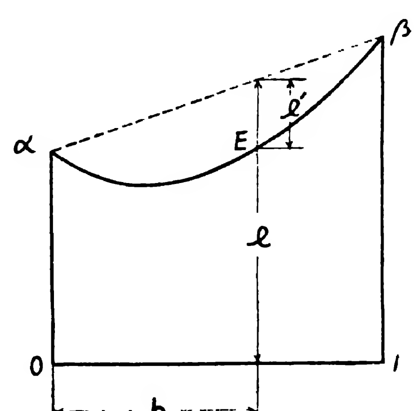
$$E = - k\, b^2 + (k + \beta - \alpha)\, b + \alpha\ . \qquad (11a)$$

This is shown by the curve in Figs. 4 and 5.



Case : k is positive.

Fig. 4.



Case : k is negative.

Fig. 5.

To find the extremum of E, we have the condition:—

$$\frac{dE}{db} = o.$$

Hence,

$$\left.\begin{aligned} a &= \frac{k+\alpha-\beta}{2k} \\ b &= \frac{k+\beta-\alpha}{2k} \end{aligned}\right\} \tag{12}$$

$$E = \frac{(k+\beta-\alpha)^2}{4k} + \alpha. \tag{13}$$

Since k has maximum value, it is necessary to have the conditions where k is positive, and $k > |\beta-\alpha|$. Let the coal consumption for evaporating the unit quantity of water be w.

Then we have

$$w = \frac{1}{E}. \tag{14}$$

If the cost of the unit quantity of coal be v, then the actual cost for evaporating the unit quantity of water, which we will call V, is as follows:—

$$V = w\,v = \frac{v}{E}. \tag{15}$$

If each unit quantity of coals A and B costs p and q, and a and b quantities of each coal are mixed, then the actual cost of mixed coal is as follows:—

$$v = p\,a + q\,b. \tag{16}$$

Applying formula (16) to the mixture of two kinds of coal with the unit quantity, we have

$$\left.\begin{aligned} a + b &= 1 \\ v &= p\,a + q\,b \end{aligned}\right\}. \tag{17}$$

Then the cost for evaporating the unit quantity of water with the mixture of two kinds of coal is as follows:—

from (11), (15) and (17)

$$\left.\begin{aligned} a + b &= 1 \\ V &= \frac{p\,a + q\,b}{\alpha\,a + \beta\,b + k\,a\,b} \end{aligned}\right\}. \tag{18}$$

Or, eliminating a between them,

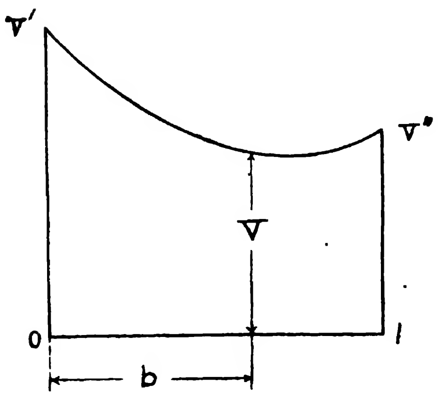
$$V = \frac{(q-p)\,b + p}{-k\,b^2 + (k+\beta-\alpha)\,b + \alpha}. \tag{18a}$$

MOST ECONOMICAL EVAPORATION WITH TWO COALS

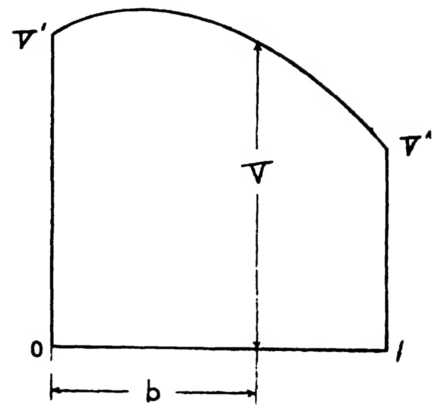
Then in the case of coals A and B, respectively, we have,

$$V' = \frac{p}{\alpha} \qquad V'' = \frac{q}{\beta} \tag{18b}$$

These are shown by the curve in Figs. 6 and 7.



Case : k is positive.
Fig. 6.



Case : k is negative.
Fig. 7.

To find the extremum of V, we have the condition:—

$$\frac{dV}{db} = o\,.$$

Hence,

$$\left.\begin{aligned} a_{ext} &= \frac{q - \sqrt{p^2 - \dfrac{q-p}{k}\left\{\alpha q - (k+\beta)\,p\right\}}}{q-p} \\ b_{ext} &= \frac{-p + \sqrt{p^2 - \dfrac{q-p}{k}\left\{\alpha q - (k+\beta)\,p\right\}}}{q-p} \end{aligned}\right\} \tag{19}$$

$$V_{ext.} = \frac{(q-p)\,b_{ext} + p}{-k\,b^2_{ext} + (k+\beta-\alpha)\,b_{ext} + \alpha} \tag{20}$$

Since V has minimum value, it is necessary to have the conditions where k is positive and $\dfrac{\beta+k}{\alpha} > \dfrac{q}{p} > \dfrac{\beta}{\alpha+k}$.

Therefore, calculating a and b from (12) and (19), *i.e.*, in evaporation or in economy, we can select the simple and convenient mixing ratio in the interval in both sets.

CASE OF MIXING THREE KINDS OF COAL

As in Case I., let the evaporation of water from the definite temperature by the unit quantities of coals A, B and C, which are burned under the same boiler under definite pressure, be α, β and γ, respectively.

In burning the above coals mixed with the quantity a, b and c the non-digestive evaporation e is as follows:—

$$e = \alpha a + \beta b + \gamma c \; . \tag{21}$$

If the quantity a, b and c are mixed together to make up the unit quantity of coal, we obtain the following equation:—

$$a + b + c = 1 \; . \tag{22}$$

So the non-digestive evaporation of water by the unit quantity of the mixture of three kinds of coal is obtained by combining (21) and (22).

$$\left.\begin{array}{l} a + b + c = 1 \\ e = \alpha a + \beta b + \gamma c \end{array}\right\} . \tag{23}$$

Or, eliminating a between them,

$$e = (\beta - \alpha)\, b + (\gamma - \alpha)\, c + \alpha \; . \tag{23a}$$

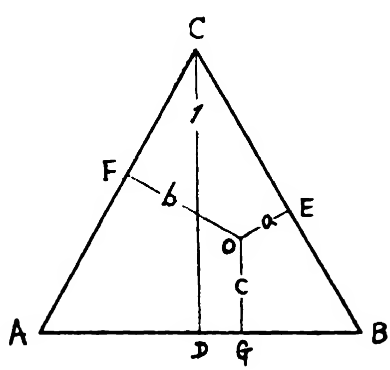


Fig. 8.

Now, as shown in Fig. 8, we know that a perpendicular CD from vertex C to the base AB of an equilateral triangle ABC is equal to the sum of three perpendiculars, OE, OF and OG to the bases from a point O taken arbitrarily in the triangle. If we assume that CD is equal to unity and OE, OF, OG are equal to a, b, c respectively, it can be said that all the cases of mixing three kinds of coal are included in the area of an equilateral triangle.

Therefore, the values of non-digestive evaporation for all the cases of the mixture of three kinds of coal with the unit quantity can be shown in the plane of a triangle defined proportionally by the value

of evaporation of the unit quantity of each coal on the perpendiculars at the three vertices of an equilateral triangle, as shown in Fig. 9.

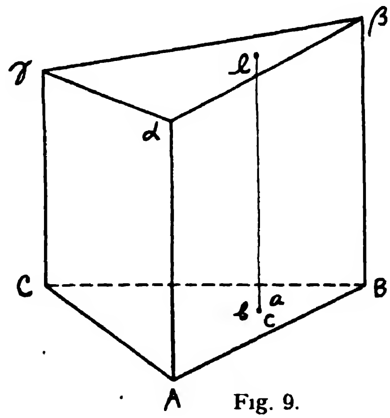


Fig. 9.

"DIGESTIVE" EVAPORATION WITH THREE COALS

As in Case I., we can consider in the mixture of three kinds of coal the digestive evaporation. Let the ability of digestion of coal A to the mixed coal of B and C be s, and simultaneously that of B to C and A, and C to A and B be t and u, respectively, and the digestive evaporation which occur in each case be ϵ_1, ϵ_2 and ϵ_3, respectively.

Then we can equate as follows:—

$$\epsilon_1 = s\int_0^a\int_0^{b+c}(dB + dC)\,dA = s\,a\,b + s\,c\,a$$

$$\epsilon_2 = t\int_0^b\int_0^{c+a}(dC + dA)\,dB = t\,b\,c + t\,a\,b$$

$$\epsilon_3 = u\int_0^c\int_0^{a+b}(dA + dB)\,dC = u\,c\,a + u\,b\,c\,.$$

So that the total digestive evaporation e' may be the sum of the above.

$$\begin{aligned} e' &= \epsilon_1 + \epsilon_2 + \epsilon_3 \\ &= (t + u)\,b\,c + (u + s)\,c\,a + (s + t)\,a\,b \end{aligned}$$

But when one of the three kinds of coal tends to approach zero the mixture narrows down to two kinds. So the terms in the brackets are the coefficients of digestive evaporation for each of the two kinds of coal. Then substituting k_1, k_2, and k_3 for these terms we have

$$\begin{aligned} t + u &= k_1 \\ u + s &= k_2 \\ s + t &= k_3 \end{aligned}$$

Hence, the digestive evaporation e' is as follows:—

$$e' = k_1 \, b \, c + k_2 \, c \, a + k_3 \, a \, b. \tag{24}$$

Applying this equation to the mixture of three kinds of coal with the unit quantity, we have

$$\left.\begin{aligned} &a + b + c = 1 \\ &e' = k_1 \, b \, c + k_2 \, c \, a + k_3 \, a \, b \end{aligned}\right\} \tag{25}$$

Or, eliminating a between them,

$$e' = - k_3 \, b^2 - (k_2 + k_3 - k_1) \, b \, c - k_1 \, c^2 + k_3 \, b + k_2 \, c. \tag{25a}$$

So that the digestive evaporation for all the cases of the mixture of three kinds of coal with the unit quantity can be shown by a curved surface on an equilateral triangle, as shown in Fig. 10.

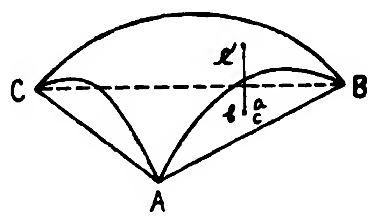


Fig 10.

To find the extremum of e' we have the following conditions:—

$$\frac{\partial e'}{\partial b} = o \qquad \frac{\partial e'}{\partial c} = o$$

Hence,

$$\left.\begin{aligned} a &= \frac{k_1 \, (k_2 + k_3 - k_1)}{2 \Sigma \, k_1 \, k_2 - \Sigma \, k_1^2} \\ b &= \frac{k_2 \, (k_3 + k_1 - k_2)}{2 \Sigma \, k_1 \, k_2 - \Sigma \, k_1^2} \\ c &= \frac{k_3 \, (k_1 + k_2 - k_3)}{2 \Sigma \, k_1 \, k_2 - \Sigma \, k_1^2} \end{aligned}\right\} \tag{26}$$

$$e' = \frac{k_1 \, k_2 \, k_3}{2 \Sigma \, k_1 \, k_2 - \Sigma \, k_1^2} \, . \tag{27}$$

Since e' has maximum value, it is necessary to have k_1, k_2 and k_3 positive, and $k_1 > |k_2 - k_3|$, $k_2 > |k_3 - k_1|$, $k_3 > |k_1 - k_2|$.

And in a special case if $k_1 = k_2 = k_3 = k$, we have

$$a_{max} = b_{max} = c_{max} = \tfrac{1}{3} \tag{28}$$

$$e'_{max} = \frac{k}{3} \, . \tag{29}$$

Best Evaporation with Three Coals

So we can say that if the coefficients of digestive evaporation of any two kinds of coal are equal or similar, each proportion of the mixture of three kinds of coal containing the greatest digestive evaporation is equal to one-third or is similar. In other words, if the coefficients of digestive evaporation of any two kinds of coal are equal or similar, the point situation of the mixture of three kinds of coal containing the greatest digestive evaporation coincides with the centre of gravity of an equilateral triangle or lies in its neighbourhood (see Fig. 11).

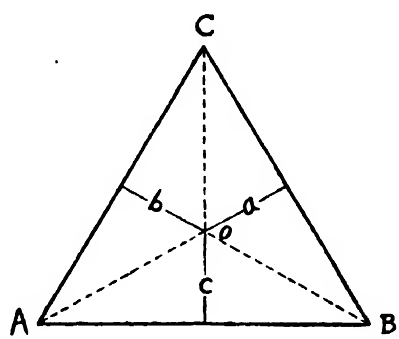


Fig. 11.

Now applying (23) and (25) to (8) we can obtain the total evaporation E.

$$\left.\begin{aligned} &a + b + c = 1 \\ &E = \alpha a + \beta b + \gamma c + k_1 b c + k_2 c a + k_3 a b \end{aligned}\right\} \tag{30}$$

Or, eliminating a between them,

$$\begin{aligned} E = &- k_3 b^2 - (k_2 + k_3 - k_1) b c - k_2 c^2 \\ &+ (k_3 + \beta - \alpha) b + (k_2 + \gamma - \alpha) c + \alpha. \end{aligned} \tag{30a}$$

So that the total evaporation can be measured by the distance from the base of an equilateral triangle to the top of the curved surface defined by the perpendiculars at three vertices which are proportional to α, β and γ respectively, as shown in Fig. 12.

To find the extremum of E we have the condition as follows:—

$$\frac{\partial E}{\partial b} = o \qquad \frac{\partial E}{\partial c} = o$$

Hence,

$$\left.\begin{aligned}
a_{ext.} &= \frac{2\,k_1\alpha-(k_1+k_2-k_3)\,\beta-(k_3+k_1-k_2)\,\gamma+k_1\,(k_2+k_3-k_1)}{2\Sigma\,k_1\,k_2-\Sigma\,k_1^2}\\
b_{ext.} &= \frac{2\,k_2\,\beta-(k_2+k_3-k_1)\,\gamma-(k_1+k_2-k_3)\,\alpha+k_2\,(k_3+k_1-k_2)}{2\Sigma\,k_1\,k_2-\Sigma\,k_1^2}\\
c_{ext.} &= \frac{2\,k_3\,\gamma-(k_3+k_1-k_2)\,\alpha-(k_2+k_3-k_1)\,\beta+k_3\,(k_1+k_2-k_3)}{2\Sigma\,k_1\,k_2-\Sigma\,k_1^2}
\end{aligned}\right\} \quad (31)$$

$$\begin{aligned}
E_{ext.} &= \alpha\,a_{ext.}+\beta\,b_{ext}+\gamma\,c_{ext}\\
&\quad+k_1\,b_{ext}\,c_{ext}+k_2\,c_{ext}\,a_{ext}+k_3\,a_{ext}\,b_{ext}
\end{aligned} \quad (32)$$

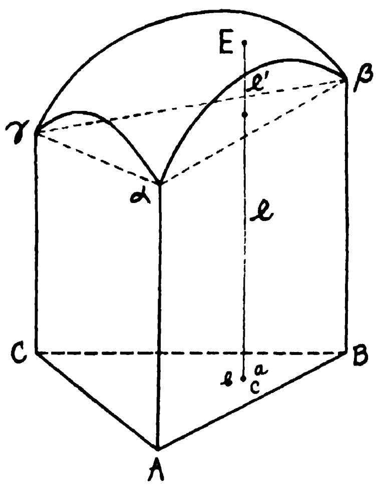


Fig. 12.

Since E has maximum value, it is necessary to have the conditions where k_1, k_2 and k_3 are positive and

$$k_1 > |k_2 - k_3|,\ k_2 > |k_3 - k_1|,\ k_3 > |k_1 - k_2|.$$

MOST ECONOMICAL EVAPORATION WITH THREE COALS

Let the cost of the unit quantities of coals, A, B and C be p, q, and r respectively, then the cost v of the mixture of three kinds of coal is as follows:—

$$\left.\begin{aligned}
a+b+c &= 1\\
v &= p\,a+q\,b+r\,c
\end{aligned}\right\} \quad (33)$$

The cost of coal consumption for evaporating the unit quantity of water by the mixture of three kinds of coal can be obtained as in (17).

$$\left.\begin{aligned}
a+b+c &= 1\\
V &= \frac{p\,a+q\,b+r\,c}{\alpha\,a+\beta\,b+\gamma\,c+k_1\,b\,c+k_2\,c\,a+k_3\,a\,b}
\end{aligned}\right\} \quad (34)$$

Or, eliminating a between them,

$$V = \frac{(q-p)\,b + (r-p)\,c + p}{-k_3 b^2 - (k_2+k_3-k_1)bc - k_2 c^2 + (k_3+\beta-\alpha)b + (k_2+\gamma-\alpha)c + \alpha} \tag{34a}$$

In the case of the coals A, B and C, respectively, we have

$$V' = \frac{p}{\alpha} \qquad V'' = \frac{q}{\beta} \qquad V''' = \frac{r}{\gamma}. \tag{34b}$$

These can be shown by the curved surface on a triangle, as seen in Fig. 13.

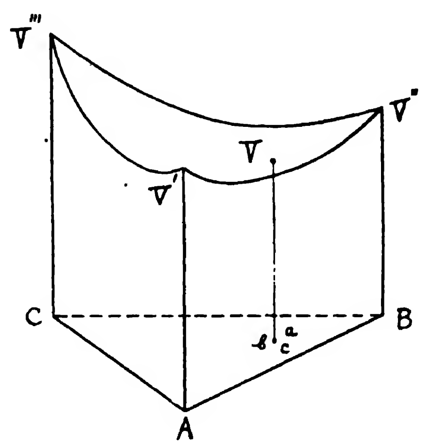


Fig 13

To find the extremum of V, we have the conditions as follows:—

$$\frac{\partial V}{\partial b} = o \qquad \frac{\partial V}{\partial c} = o.$$

Solving the above equations, we obtain

$$k_3\,(q-p)\,b^2 - 2k_3\,(p-r)\,b\,c + [(k_1-k_3)\,(p-r) + k_2\,(r-q)]\,c^2 + 2k_3\,p\,b$$
$$+ \begin{bmatrix} (k_2+k_3-k_1)\,p \\ +(k_2+\gamma-\alpha)\,(q-p) \\ +(k_3+\beta-\alpha)\,(p-r) \end{bmatrix} c + [\alpha\,q - (k_3+\beta)\,p] = o \tag{i}$$

$$[(k_2-k_1)\,(q-p) - k_3\,(r-q)]\,b^2 + 2k_2\,(q-p)\,b\,c - k_2\,(p-r)\,c^2$$
$$+ \begin{bmatrix} (k_2+k_3-k_1)\,p \\ -(k_2+\gamma-\alpha)\,(q-p) \\ -(k_3+\beta-\alpha)\,(p-r) \end{bmatrix} b + 2k_2\,p\,c + [\alpha r - (k_2+\gamma)\,p] = o \tag{ii}$$

Instead of (i) and (ii), put coefficients as follows:—

$$D\,b^2 + F\,b\,c + G\,c^2 + H\,b + I\,c + J = o \tag{ia}$$
$$D'\,b^2 + F'\,b\,c + G'\,c^2 + H'\,b + I\,c' + J' = o \tag{iib}$$

From the above simultaneous equations, we have

$$b = \frac{(D\,G' - D'\,G)\,c^2 + (D\,I' - D'\,I)\,c + (D\,J' - D'\,J)}{(D'\,F - D\,F')\,c + (D'\,H - D\,H')} \qquad \text{(iii)}$$

changing (34) as follows:—

$$\phi = a + b + c - 1 = o$$

$$V = \frac{p\,a + q\,b + r\,c}{\alpha\,a + \beta\,b + \gamma\,c + k_1\,b\,c + k_2\,c\,a + k_3\,a\,b}\,.$$

For the extremum of V, we have the following conditions:—

$$\frac{\partial V}{\partial a} + \lambda\frac{\partial \phi}{\partial a} = o \qquad \frac{\partial V}{\partial b} + \lambda\frac{\partial \phi}{\partial b} = o \qquad \frac{\partial V}{\partial c} + \lambda\frac{\partial \phi}{\partial c} = o\,,$$

Hence,

$$\frac{q-p}{k_3a-k_3b+(k_1-k_2)c+\beta-\alpha} = \frac{r-q}{(k_2-k_3)a+k_1b-k_1c+\gamma-\beta} \qquad \text{(iv)}$$

Substituting $1 - b - c$ for a in the above

$$\begin{aligned} &\left\{ (k_1 - k_2)\,(q - p) - k_3\,(p + q - 2\,r) \right\} b \\ +&\left\{ (k_1 - k_3)\,(p - r) + k_2\,(p + r - 2q) \right\} c \\ +&\left\{ (k_2 - k_3 + \gamma - \beta)\,(q - p) - (k_3 + \beta - \alpha)\,(r - q) \right\} = o. \end{aligned} \qquad \text{(v)}$$

Thence, substituting (iii) in the above,

$$\begin{aligned} &\begin{bmatrix} (DG'-D'G)\left\{ (k_1-k_2)\,(q-p)-k_3\,(p+q-2r) \right\} \\ +(D'F-DF')\left\{ (k_1-k_3)\,(p-r)+k_2\,(p+r-2q) \right\} \end{bmatrix} c^2 \\ +&\begin{bmatrix} (DI'-D'I')\left\{(k_1-k_2)\,(q-p)-k_3\,(p+q-2r)\right\} \\ +(D'H-DH')\left\{(k_1-k_3)\,(p-r)+k_2\,(p+r-2q)\right\} \\ +(D'F-DF')\left\{k_2-k_3+\gamma-\beta)\,(q-p)-(k_3+\beta-\alpha)\,(r-q)\right\} \end{bmatrix} c \\ +&\begin{bmatrix} (DJ'-D'J)\left\{(k_1-k_2)\,(q-p)-k_3\,(p+q-2\,r)\right\} \\ +(D'H-DH')\left\{(k_2-k_3+\gamma-\beta)(q-p)-(k_3+\beta-\alpha)(r-q)\right\} \end{bmatrix} = o \end{aligned} \qquad \text{(vi)}$$

Putting the coefficients P, Q and R for those of the above

$$P\,c^2 + Q\,c + R = o \qquad \text{(vi } a\text{)}$$

Hence,

$$c = \frac{-Q \pm \sqrt{Q^2 - 4\,P\,R}}{2\,P} \qquad \text{(vii)}$$

where it is necessary to have the condition

$$1 > \frac{-Q \pm \sqrt{Q^2 - 4\,P\,R}}{2\,P} > o$$

Then substituting (vii) into (iii), we can obtain b and after that a can easily be found. (35)

The value of V can be obtained by substituting the above a, b and c into (34). And since V has minimum value, it is necessary to have the conditions where k_1, k_2, and k_3 are positive and

$$1 > \frac{-Q \pm \sqrt{Q^2 - 4PR}}{2P} > o \tag{36}$$

As in Case I, we can select the simple and convenient mixing ratio for the three kinds of coal from (31) and (35).

GENERAL CASE OF MIXING COAL

Suppose that the unit quantity of mixed coals consists of n kinds, A_1, A_2, . . . A_n, and let each portion be a_1, a_2, ... a_n, the evaporation of each coal with the unit quantity be α_1, α_2, . . . α_n, and the coefficients of digestive evaporation between the two different kinds of coal be k_{12}, k_{13}, ... $k_{n-1,\,n}$, respectively. Then the total digestive evaporation e' is as follows:—

$$\left.\begin{aligned} & a_1 + a_2 + \;.\;.\;.\;.\;.\; + a_n = 1 \\ & e' = k_{12}\, a_1 a_2 + k_{13}\, a_1 a_3 + \;.\;.\;.\;.\;.\; + k_{n-1,\,n}\, a_{n-1} a_n \end{aligned}\right\} \tag{37}$$

And the evaporation E is as follows:—

$$\left.\begin{aligned} & a_1 + a_2 + \;.\;.\;.\;.\; + a_n = 1 \\ & E = \alpha_1 a_1 + \alpha_2 a_2 + \;.\;.\;.\;.\; + \alpha_n a_n \\ & + k_{12}\, a_1 a_2 + k_{13}\, a_1 a_3 + \;.\;.\;.\;.\; + k_{n-1,\,n}\, a_{n-1} a_n \end{aligned}\right\} \tag{38}$$

Let the cost of the unit quantities of coal be p_1, p_2, ... p_n, respectively. Then the cost V for evaporation of the unit quantity of water by the above mixture of n kinds of coal is as follows:—

$$\left.\begin{aligned} & a_1 + a_2 + \;.\;.\;.\;.\; + a_n = 1 \\ & V = \frac{p_1 a_1 + p_2 a_2 + \;.\;.\;.\;.\; + p_n a_n}{\alpha_1 a_1 + \alpha_2 a_2 + \ldots + \alpha_n a_n + k_{12} a_1 a_2 + k_{13} a_1 a_3 + \ldots + k_{n-1\,n} a_{n-1} a_n} \end{aligned}\right\} \tag{39}$$

Here in each case of the coals A_1, A_2, . . . A_n, respectively, we have

$$V' = \frac{p_1}{\alpha_1} \qquad V'' = \frac{p_2}{\alpha_2} \;.\;.\;.\;.\; V^{(n)} = \frac{p_n}{\alpha_n} \tag{39a}$$

In the case of (37) if k_{12}, k_{13}, ... $k_{n-1,\,n}$ are positive and $k_{12} = k_{13} = \ldots k_{n-1,\,n} = k$, then the greatest digestive evaporation of mixed coal may be kept in the case of $a_1 = a_2 = \;.\;.\;.\;.\; = a_n$. Hence,

$$e'_{max.} = \frac{\binom{n}{2}}{n^2}\, k = \tfrac{1}{2}\left(1 - \frac{1}{n}\right) k \tag{40}$$

If n approaches infinity, the above equation becomes:—

$$e'_{max.} = \tfrac{1}{2}\, k \tag{41}$$

And if n is equal to one, $e'_{max.}$ becomes zero. The mathematical meaning shows that it is the case of the combustion of the unit quantity of one kind of coal and no mixture, so that the digestive evaporation must be zero.

Now take the equation $y=\frac{1}{2}\left(1-\frac{1}{x}\right)k$, and let us plot on its curve the value of e'_{max} and n obtained from (40).

Then we have Fig. 14.

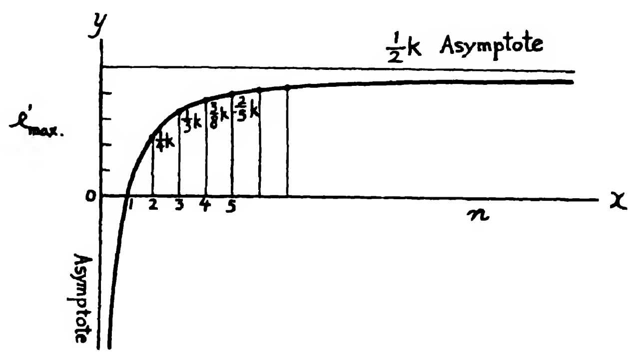


Fig. 14.

Therefore, we can say that the value of the evaporation gained from the digestive action of mixed coal cannot be in any case beyond the half of the greatest coefficient of digestive evaporative contained in their combinations.

NUMERICAL EXAMPLE I: CASE OF MIXING TWO KINDS OF COAL

Burning the mixture of one-half of A and one-half of B kinds of coal under a boiler, we get the results as follows:—

$$\alpha = 6{\cdot}44 \qquad \beta = 9{\cdot}20 \qquad E_{(\cdot5+\cdot5)} = 9{\cdot}06\,.$$

Then, calculating from (9), $k = 4{\cdot}96$.

Hence the evaporation from (11)

$$E = -4{\cdot}96\,b^2 + 7{\cdot}72\,b + 6{\cdot}44\,,$$

from (12) and (13)

$$\left.\begin{aligned} a &= 0{\cdot}22 \\ b &= 0{\cdot}78 \end{aligned}\right\} \text{(I)}$$

$$E_{max} = 9{\cdot}44$$

Let the cost of coal per 1,000 Kg. be as follows:—

$$p = 800 \text{ sen} \qquad q = 1{,}000 \text{ sen}$$

Hence the cost of coal consumption for evaporating 1,000 Kg. of water from (18b) and (18a)

$$V' = \frac{p}{\alpha} = 124{\cdot}22 \text{ sen} \qquad V'' = \frac{q}{\beta} = 108{\cdot}70 \text{ sen}$$

$$V = \frac{200\,b + 800}{-4{\cdot}96\,b^2 + 7{\cdot}72\,b + 6{\cdot}44} \text{ sen};$$

from (19) and (20)

$$\left.\begin{aligned} a &= 0{\cdot}43 \\ b &= 0{\cdot}57 \end{aligned}\right\} \text{(II)}$$

$$V_{min} = 99{\cdot}04 \text{ sen}.$$

Comparing the results (I) and (II) we can select the mixing ratio thus

$$a = 0{\cdot}3 \qquad b = 0{\cdot}7$$

$$\text{or} \quad a = 0{\cdot}4 \qquad b = 0{\cdot}6 .$$

Therefore, in the two sets, the former is more effective than the latter, and the latter is more economical than the former.

Numerical Example 2: Case of Mixing Three Kinds of Coal

In mixing three kinds of coal A, B and C we get the following results according to trials:—

$$\alpha = 6{\cdot}44 \qquad \beta = 9{\cdot}20 \qquad \gamma = 6{\cdot}22$$

$$k_1 = 5{\cdot}72 \qquad k_2 = 3{\cdot}48 \qquad k_3 = 4{\cdot}96 .$$

Then from (30a)

$$E = -4{\cdot}96\,b^2 - 2{\cdot}72\,b\,c - 3{\cdot}48\,c^2 + 7{\cdot}72\,b + 3{\cdot}26\,c + 6{\cdot}44,$$

from (31) and (32)

$$\left.\begin{aligned} a &= 0{\cdot}09 \\ b &= 0{\cdot}73 \\ c &= 0{\cdot}18 \end{aligned}\right\} \text{(I)}$$

$$E_{max} = 9{\cdot}55 .$$

Let the cost of coal per 1,000 Kg. be as follows:—

$$p = 800 \text{ sen} \qquad q = 1{,}000 \text{ sen} \qquad r = 900 \text{ sen}.$$

Hence, the cost of coal consumption for evaporating 1,000 Kg. of water from (34b) and (34a)

$$V' = \frac{p}{\alpha} = 124{\cdot}22 \text{ sen} \quad V'' = \frac{q}{\beta} = 108{\cdot}70 \text{ sen} \quad V''' = \frac{r}{\gamma} = 144{\cdot}69 \text{ sen}$$

$$V = \frac{200\,b + 100\,c + 800}{-4{\cdot}96\,b^2 - 2{\cdot}72\,bc - 3{\cdot}48\,c^2 + 7{\cdot}72\,b + 3{\cdot}26\,c + 6{\cdot}44} \text{ sen}.$$

From (35) and (36)

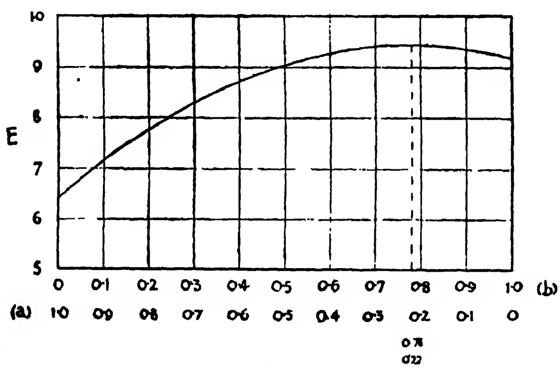
$a = 0{\cdot}35$
$b = 0{\cdot}54$
$c = 0{\cdot}11$
$V_{min.} = 96{\cdot}63$ sen.

By comparing the results (I) and (II), we can select the mixing ratio thus

$a = 0{\cdot}3 \qquad b = 0{\cdot}6 \qquad c = 0{\cdot}1$
or $a = 0{\cdot}2 \qquad b = 0{\cdot}7 \qquad c = 0{\cdot}1.$

Therefore, in the two sets, the former is more economical than the latter and the latter is more effective than the former.

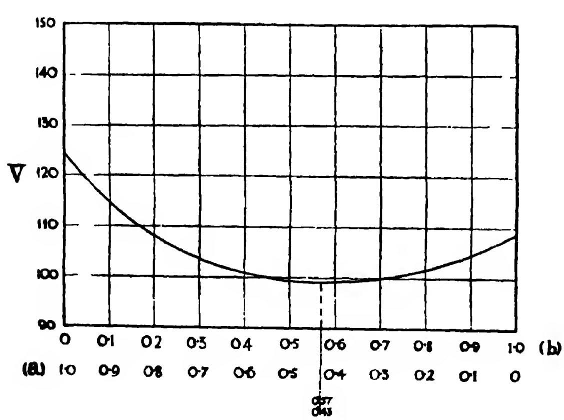
The above examples (I) and (II) can be shown more precisely by means of graphs, as seen from Fig. 15 to Fig. 18.



Ratio of mixed coal.		Equivalent evaporation.	
a	b	E	
1·0	0	6·4400	
0·9	0·1	7·1634	
0·8	0·2	7·7856	
0·7	0·3	8·3096	
0·6	0·4	8·7344	
0·5	0·5	9·0500	
0·4	0·6	9·2864	
0·3	0·7	9·4136	
0·22	0·78	9·4439	Maximum
0·2	0·8	9·4416	
0·1	0·9	9·3704	
0	1·0	9·2000	

Fig. 15

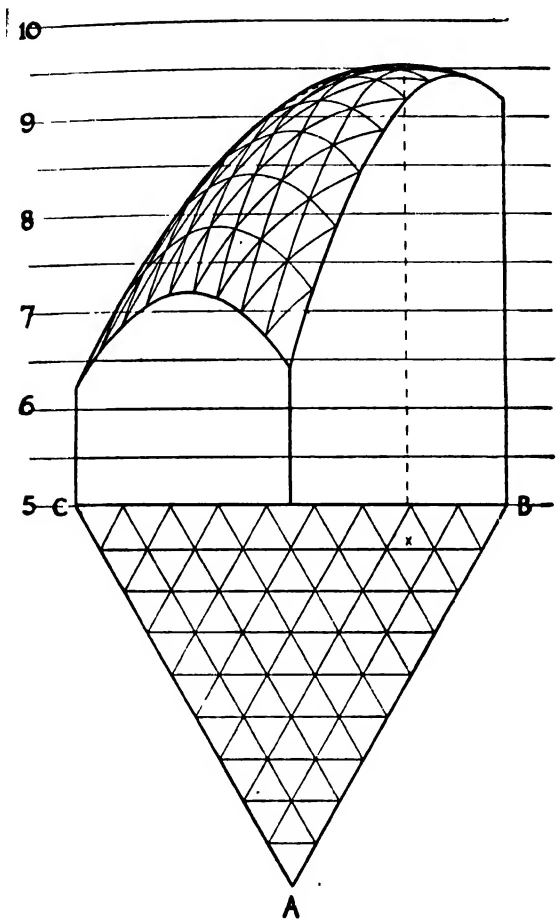
Evaporation of mixed coal ($A+B$).



Ratio of mixed coal		Cost of mixed coal per 1,000 Kg	Cost of mixed coal consumption per 1,000 Kg of equivalent evaporation	
a	b	v	$V = \frac{v}{E}$	
		Sen	Sen	
1·0	0	800	124·22	
0·9	0·1	820	114·47	
0·8	0·2	840	107·89	
0·7	0·3	860	103·49	
0·6	0·4	880	100·75	
0·5	0·5	900	99·34	
0·43	0·57	—	99·04	Minimum
0·4	0·6	920	99·07	
0·3	0·7	940	99·86	
0·2	0·8	960	101·68	
0·1	0·9	980	104·58	
0	1·0	1,000	108·70	

Fig. 16.

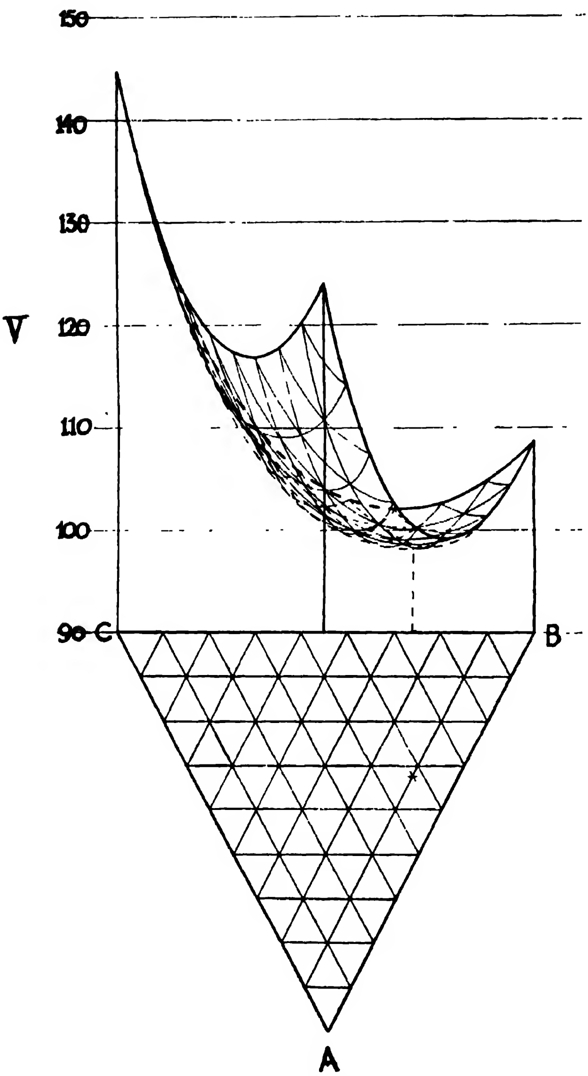
Cost of mixed coal ($A+B$) consumption per 1,000 Kg. of equivalent evaporation.



Ratio of mixed coal.			Equivalent evaporation.
a	*b*	*c*	*E*
0	0	1	6·2200
1	0	0	6·4400
0	1	0	9·2000
1 : 9	1 : 9	7 : 9	7·4319
2 : 9	2 : 9	5 : 9	8·3119
1 : 9	4 : 9	4 : 9	9·1156
2 : 9	5 : 9	2 : 9	9·4148
0·81 : 9	6·57 : 9	1·62 : 9	9·5491 Maximum
1 : 9	7 : 9	1 : 9	9·5281
4 : 9	4 : 9	1 : 9	9·0763
3 : 9	3 : 9	3 : 9	8·8044
5 : 9	2 : 9	2 : 9	8·3289
4 : 9	1 : 9	4 : 9	7 8637
7 : 9	1 : 9	1 : 9	7·5222

Fig. 17.

Evaporation of mixed coal ($A+B+C$).



Ratio of mixed coal.			Cost of mixed coal per 1,000 Kg.	Cost of mixed coal consumption per ...
a	b	c	v	V=
			Sen	Se
0	0	1	900 00	14[illegible]
1	0	0	800·00	12[illegible]
0	1	0	1000·00	10[illegible]
1 : 9	1 · 9	7 : 9	900·00	12[illegible]
2 : 9	2 : 9	5 : 9	900·00	10[illegible]
1 : 9	4 : 9	4 : 9	933·33	10[illegible]
1 : 9	7 : 9	1 : 9	966·67	10[illegible]
2 : 9	5 : 9	2 : 9	933·33	99
3·15 : 9	4 86 : 9	0 99 : 9	—	98 Minim[illegible]
4 : 9	4 . 9	1 9	900·00	99 [illegible]
3 : 9	3 · 9	3 : 9	900 00	101 5
5 . 9	2 · 9	2 · 9	866·67	104 9
4 : 9	1 : 9	4 · 9	866·67	110 2
7 : 9	1 : 9	1 . 9	833·33	110 7

Fig. 18.

Cost of mixed coal $(A+B+C)$ consumption per 1,000 Kg. of equivalent evaporation.

ZUSAMMENFASSUNG.

Die vorgeschlagenen Formeln dienen dazu, die günstigsten Proportionen einer Kohlenmischung, die als Brennmaterial in Dampfkesseln verwendet werden soll, zu finden, und zwar sowohl in Bezug auf die Verdampfung als auch auf die Wirtschaftlichkeit.

In dieser Absicht habe ich angenommen, dass die Verdampfung der gemischten Kohle der Summe der Verdampfungen ihrer Teile gleich ist, mit der Zugabe einer Extra-Verdampfung, die durch das Brennen der gemischten Kohle entsteht. So habe ich fur diese Extra-Verdampfung den Ausdruck "die beförderte Verdampfung" angewandt und den Koeffizienten derselben zwischen zwei verschiedenen Sorten Kohle festgestellt.

Dann habe ich die bezuglichen Gleichungen zwischen der Verdampfung und der Kohlenmischung zusammengestellt, mit Rücksicht auf zwei, drei oder mehr Sorten Kohle, und habe die Formel fur ihre Maxima Minima angegeben.

Wenn wir deshalb die Resultate der Untersuchungen anwenden, nämlich die Verdampfung jeder Sorte Kohle und den Koeffizienten der beförderten Verdampfung, so konnen wir leicht das Verhaltnis der Kohlenmischung finden, die das Maximum der Verdampfung enthalten wird.

Um anhand der Marktpreise die geringsten Unkosten zu erlangen, können wir das Verhältnis der anderen Kohlenmischung auf dieselbe Weise finden.

So endlich können wir, von den beiden vorerwähnten Sorten der idealen Mischung ausgehend, diejenige fur die praktische Anwendung wählen, welche passend und in runden Ziffern sein wird.

THE APPLICATION OF AIR-COOLED CONDENSERS TO LOCOMOTIVES

SWEDISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

ALF. LYSHOLM

Paper No. J14

CONTENTS

It is generally supposed that direct air-cooled condensers of great capacity cannot be built for locomotives, owing to the small space that can be utilised within the rolling-stock gauge. Researches have shown, however, that it is possible to obtain sufficient cooling area within a very small space by using especially effective condenser elements, and recently a locomotive condenser of this type has been developed.

The first experiments were made with cooling elements designed according to Figs. 1, 2 and 3. The width of the elements in the direction of the air flow was about 100 mm. The cooling elements were built up of flat copper pipes provided with straight fins, the slope of the fins being such that crossing air currents were formed. By this means, a very high coefficient of heat transfer was obtained, which, in combination with the large cooling area, gives the desired result.

Tests have been made with a slope of 30° of the fins as well as a slope of 15°. Owing to the crossing air currents the coefficient of heat transfer will be practically constant along the direction of the air flow. It is thus easy to calculate the cooling effect and the efficiency of the elements at different widths, assuming constant temperature on the steam side.

The following letters are used in the formulae:—

Q = Quantity of heat in calories.
a = Coefficient of heat transfer.
t_1 = Temperature difference between steam and incoming air.
t_2 = Temperature difference between steam and outgoing air.
t = Temperature difference.
z = Time.
b = Width of elements.

FIG. 1

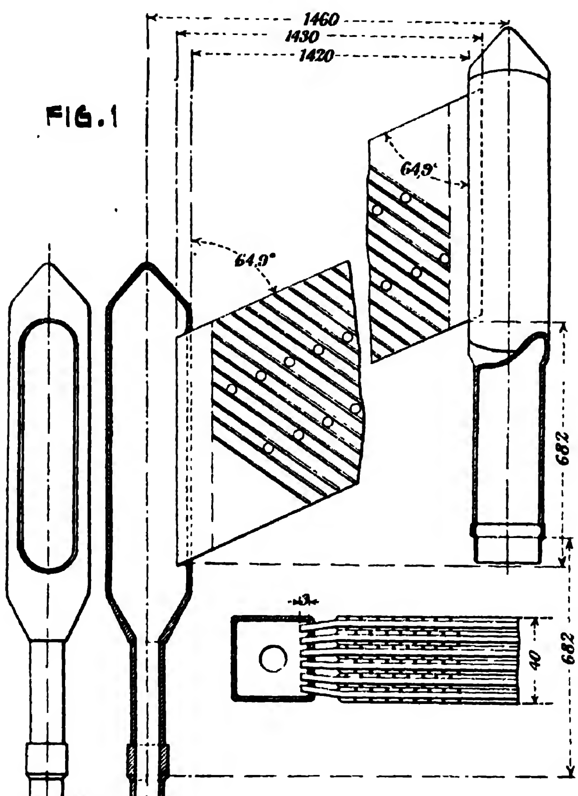


Fig. 1.—Condenser elements for the experimental locomotive.

c_p = Specific heat of air.
G = Air quantity.
η = Efficiency.
c_1 ≐ Circumference of elements cooled by air.

The heat transmitted by convection is equal to the heat corresponding to the increasing temperature of the air. This gives the following equation:—

$$dQ = a \cdot c_1 \cdot z \cdot t \cdot db = c_p \cdot G \cdot dt.$$

FIG.2.

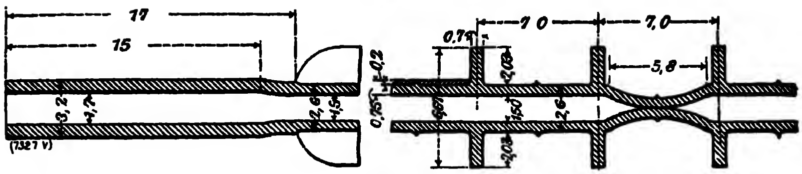


Fig. 2.—Section of condenser element.

This equation can be simplified if the relation between b and t only is calculated. Thus:—

$$b = c \int_{t_1}^{t_2} \frac{dt}{t}$$

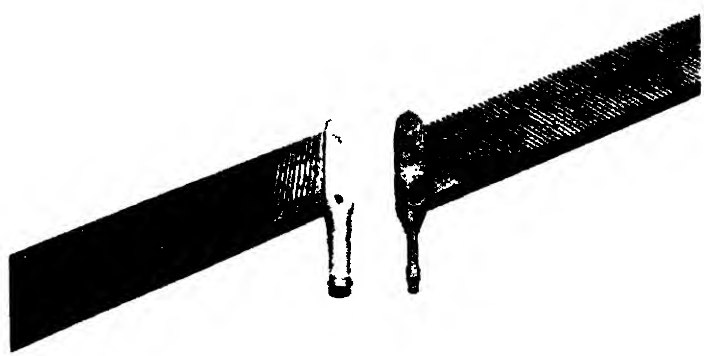


Fig. 3.—External view of condenser element for the experimental locomotive.

$$b = c \, . \, \ln \frac{t_2}{t_1}$$

$$\text{If } \eta = \frac{t_1 - t_2}{t_1}$$

$$b = c \, . \, \ln (1 - \eta)$$

Finally, $1 - \eta_2 = (1 - \eta_1)^{b_2/b_1}$ where η_1 and η_2 correspond to the widths b_1 and b_2.

In Fig. 4 the efficiency and resistance values with 100 mm. elements, arrived at in the test, are drawn as functions of the air quantity in cubic metres per square metre of front area. The front area is not the useful cross-sectional area of the air flow but the total area taken up by the elements. From this curve the efficiency and the

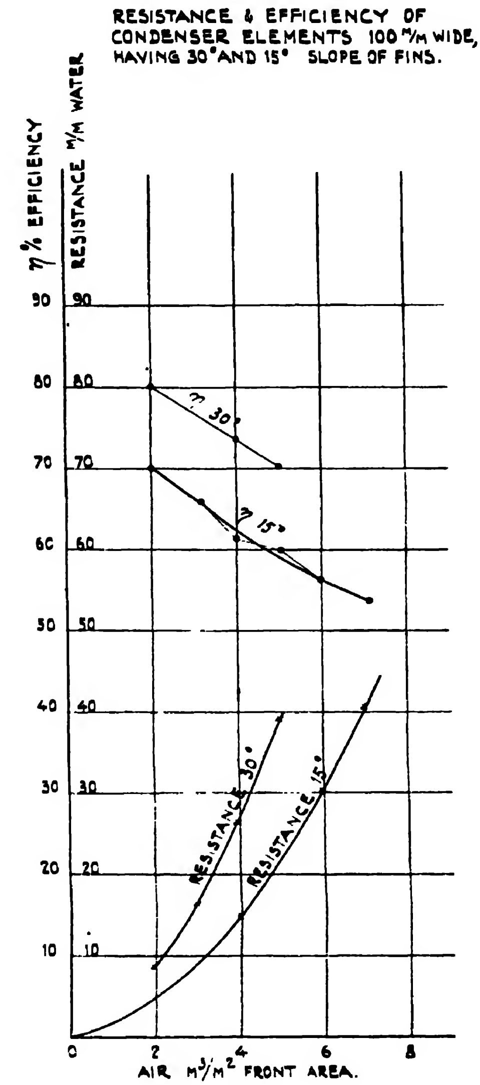


Fig. 4.

resistance for different widths and 15° slope of the fins have been calculated and are shown in Fig. 5. This figure shows that 150 mm. elements and 15° slope are superior to 100 mm. elements and 30° slope.

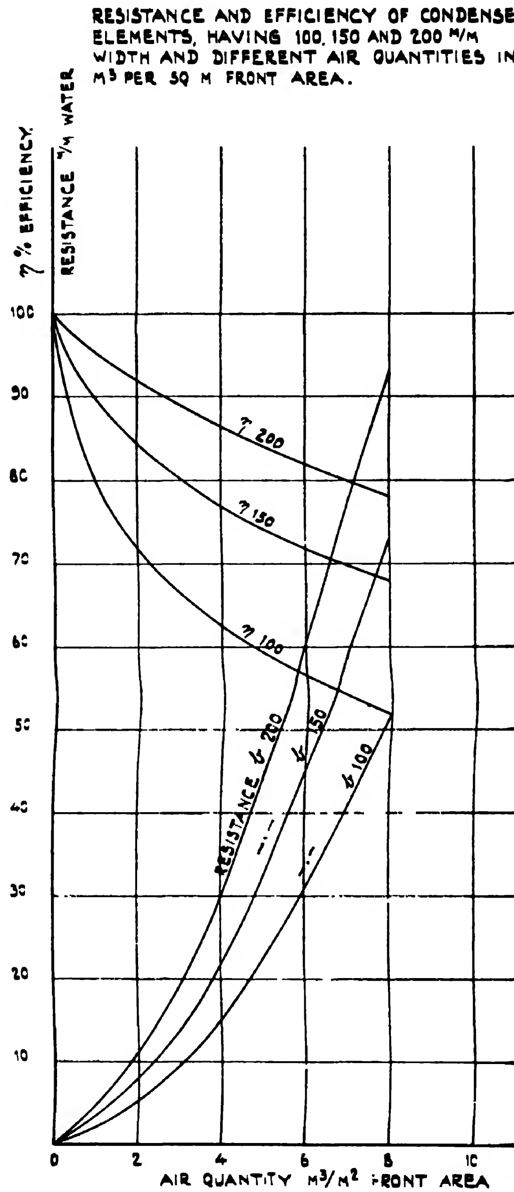


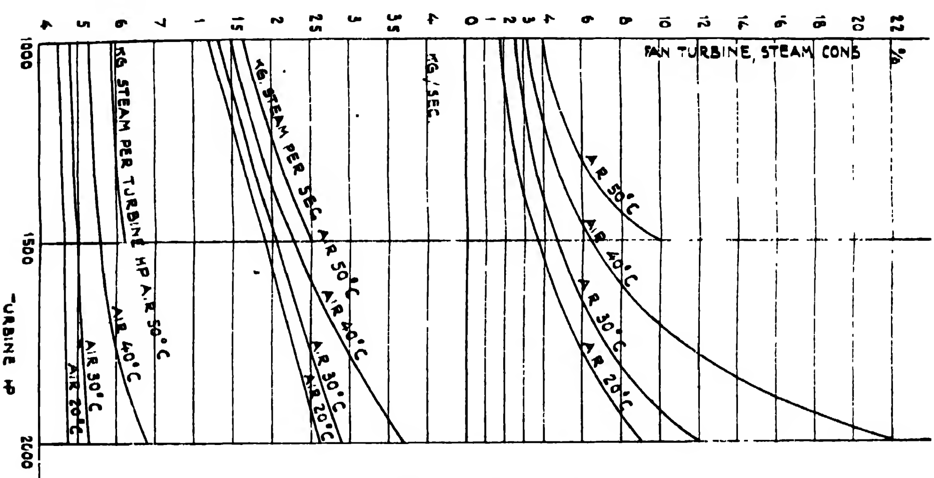
Fig. 5.

The result is still better with elements of a width of 200 mm., and the following calculation is made for elements of this size, conditions being assumed to be as follows:—

Steam pressure before the turbine	18 Kg. per sq. cm.
Steam temperature	400°C.
Air temperature	from 20° to 50°C.
The steam fed to the draught fans is supposed to be	5 per cent. of the total condensed steam.

The turbine for the condenser fans is supposed to give the same efficiency as the main turbine. To the resistance obtained from the curve in Fig. 5, an extra resistance is added for other losses, which are supposed to be 20 mm. of water at 8 cu. m. per square metre. The calculation is made only for the steam that is condensed. The steam supplied to other auxiliaries, such as feed pumps, ejectors, etc., is condensed by the feed water at least during continuous full load.

The figures are valid for continuous full load only, without taking into consideration the accumulating effect of the water in the condenser vessel. In order to simplify the calculations, temperature



STEAM CONSUMPTION PER TURBINE HP HOUR
— " — — " — IN KG PER SEC.
— " — — " — OF FAN TURBINE IN % OF CONDENSED STEAM QUANTITY
WIDTH OF ELEMENT 200 M/M, SLOPE 15° FRONT AREA 30 M².
TEMP DIFFERENCE 40° C BETWEEN INCOMING AIR AND STEAM

Fig. 6.

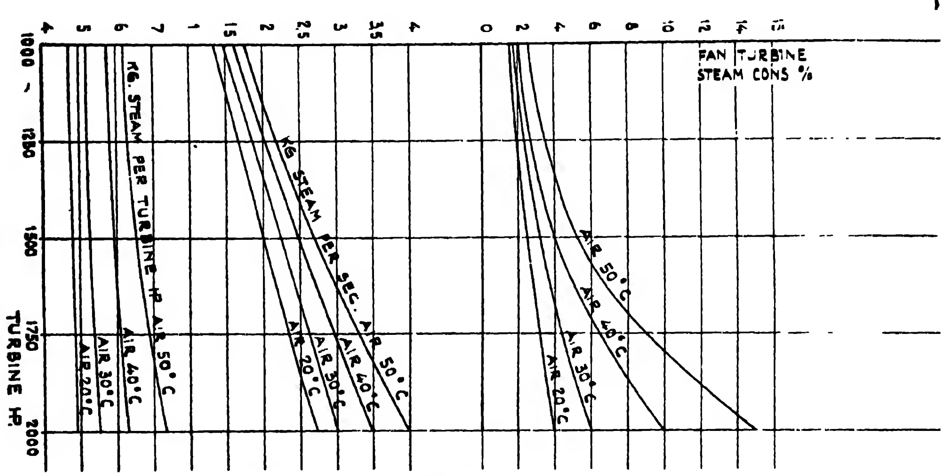
differences between incoming air and steam of 40° to 50°C., respectively, are considered. The total front area of the condenser is supposed to be 30 sq. m., which approximately corresponds to the size made for the Beyer, Peacock, the Swedish State Railways, and the Argentine State Railways locomotives.

In Figs. 6 and 7 the total steam consumption, the steam consumption in Kg. per H.P.hr., and the percentage of steam consumed by the fan turbine, are indicated as functions of the output from the main turbine and coupling. As an example, for 50°C. temperature difference, 40°C. air temperature and 2,000 H.P., the steam consumption per H.P.hr. will be 6·3 Kg., the total steam quantity being 3·5 Kg.

per second. This steam quantity is condensed by using only 10 per cent. of the total steam passing to the fan turbine.

If the air temperature is increased to 50°C. and the maximum steam quantity from the boiler is limited to 3·5 Kg. per second, the maximum output will be 1,850 H.P., a decrease of only 7·5 per cent. For a temperature difference of 40°C. and an air temperature of 40°C., the consumption of steam will be 6·8 Kg. per H.P.hr., with a total steam quantity of 3·7 Kg. per second. The percentage of steam absorbed by the fan turbine is, however, increased to 22 per cent.

Fig. 8 shows the optimum values taken from Figs. 6 and 7. It will be seen that the steam consumption is very little influenced by the



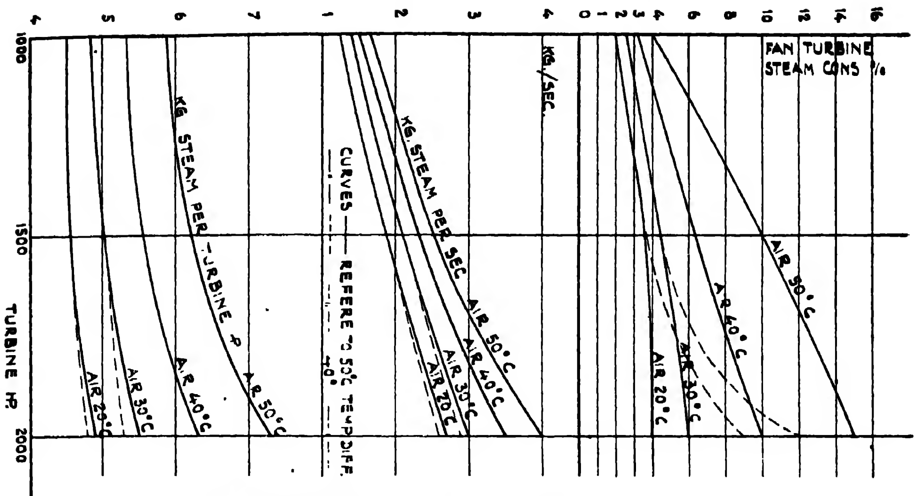
STEAM CONSUMPTION PER TURBINE HP HOUR
IN KG PER SEC.
OF FAN TURBINE IN % OF CONDENSED STEAM QUANTITY
WIDTH OF ELEMENT 200 M/M, SLOPE 15°, FRONT AREA 30 M².
TEMP DIFFERENCE 50°C BETWEEN INCOMING AIR AND STEAM

Fig. 7.

load of the fan turbine at outputs below 1,700 H.P. Under high loads on the fan turbine, *i.e.*, corresponding to 40°C temperature difference, a better vacuum is obtained, but the higher output per Kg. of steam, owing to the larger heat drop, is counterbalanced by the increased power needed for the condenser fans. At the maximum output, however, the lower load on the fan turbine, *i.e.*, at 50°C. temperature difference, is superior.

The back pressures obtained by the different methods of running the fan turbine are indicated in Fig. 9.

Generally, a locomotive does not utilise a continuous full load, because a certain margin in power is needed for making up lost



STEAM CONSUMPTION PER TURBINE HP HOUR
— · — ---·-- IN KG PER SEC.
- · - --· - OF FAN TURBINE IN % OF CONDENSED STEAM QUANTITY
WIDTH OF ELEMENT 200 M/M, SLOPE 15°, FRONT AREA 30 M².
TEMP DIFFERENCE 40° RESP 50°C BETWEEN INCOMING AIR AND STEAM.

Fig. 8.

time. As a rule, the maximum power will be about 80 per cent. of the full load capacity. In this case and taking an air temperature of 50°C., the steam consumption will be reduced to 6·35 Kg. per H.P.hr., which must be considered very satisfactory.

CONDENSER PRESSURES AT DIFFERENT AIR TEMPERATURES AND FOR TEMP. DIFF. BETWEEN INCOMING AIR AND STEAM OF 40° AND 50°C RESPECTIVELY.

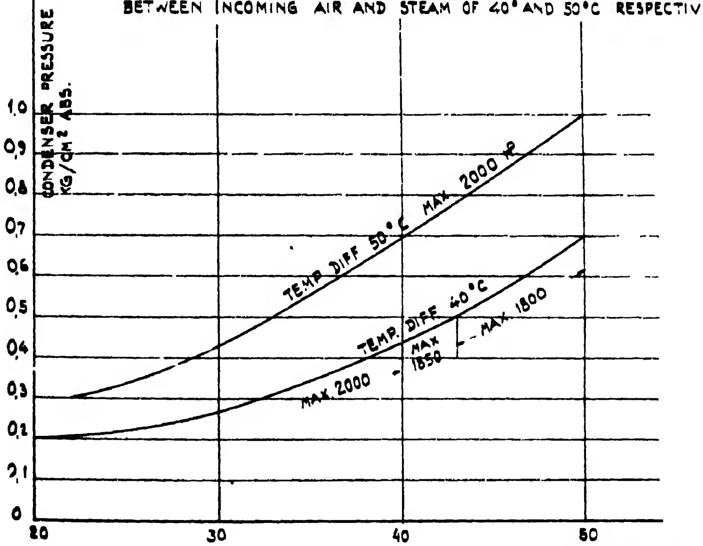


Fig. 9.

TABLE 1.—TESTS WITH THE CONDENSER OF THE ARGENTINE LOCOMOTIVE, Sept. 15th, 1925

Time.	D=32·8 mm. Area 8·45 sq. cm. Steam pressure before measuring nozzle of condenser Kg. per sq. cm.	Steam pressure at fan turbine Kg. per sq. cm.	Water lifter steam pressure at small air ejector Kg. per sq. cm.	Temp. before measuring nozzle of condenser deg. C.	Temp. in collecting pipes deg. C.	Temp. of water in condenser vessel deg. C.	Temp. in water lifter deg. C.	Vacuum cm. of mercury.	Air temp. before elements right side, deg. C.	Air temp. before elements left side, deg. C.	Steam pressure at induced draught fan, Kg. per sq. cm.	Remarks
12·20	8·7	15		190	73	75		45				start
12·25	9	15		191	74	76		45				
12·30	9	15		176	73	76		46			6	
12·35	9	15		190	74	76		46				stop
3·15	11·4	16	16·5	200	71	75		45		31	6·5	start
3·20	11·2	16·5	17	200	76	78		41·5			8	
3·25	11·8	17·2	17	204	78	81	78	39	41·7		8·5	
3·30	11·8	17·3	17	204	79	81	77	39·5		32·5	8·3	
3·35	11·8	17·5	17	204	77·5	80	77	40·5			8·3	
3·40	11·8	17·2	17	204	78	80	77	40	43·6		8·4	
3·45	11·8	17·3	17	204	78	80	78	40		34·6	8·4	
3·50	11·8	17·4	17·4	204	78	80	78	40·5			8·5	
3·55	12	17·5		204				40·5	44·6		8·4	
4·00	12	17·5		204				40		32·5	8·4	
4·05	12	17·5		204				39	45·5		8·3	
4·10												stop

The average load of a locomotive does not generally exceed 50 per cent., and as a rule, the load changes very often owing to gradients, speed reductions, etc. Thus the accumulating condenser used by the Ljungström Company, is of a very great value, and results in this: that the average steam consumption is more correctly calculated at the average load and not at the continuous full load. The actual steam consumption, therefore, will be considerably lower and corresponds to 5·85, 5·3, 4·8, 4·5 Kg. per H.P.hr. at 50, 40, 30 and 20°C. air temperature, respectively. This investigation shows that it is possible to obtain sufficient power even at such abnormal temperatures as 50°C., and that the steam consumption in such a case also has a reasonable value.

For calculation of the total fuel consumption per year, the mean temperature of the air should be used. Even for such a hot climate as the Sahara Desert the mean temperature is not higher than about 25°C. The average fuel consumption during the year should be calculated at this temperature, giving a steam quantity of about 4·7 Kg. per H.P.hr.

The turbine locomotives of the Ljungström type now running are provided with 150 mm. elements. The condenser fans are not driven in such a way that the full efficiency of the main turbine can be attained. The figures mentioned above, therefore, cannot be fully obtained by the present locomotives.

Table I. shows a test carried out with the Argentine locomotive, built by Messrs. Nydqvist & Holm Aktiebolag, at Trollhätten. This locomotive is provided with a front area of the condenser of 28 sq. m., and is designed for the following steam conditions:—

Steam pressure	18 Kg. per sq. cm. abs.
Steam temperature	375° C.
Back pressure	0·7 Kg. per sq. cm. abs.
At an air temperature of	40°C.
And an output of	1,480 H.P.
Back pressure	0·3 Kg. per sq. cm. abs.
At an air temperature of	20°C.
And an output of	1,870 H.P.

In order to obtain a sufficiently high air temperature the tests were carried out in a partly-closed shed with shutters, by which means the air temperature could be regulated. The steam quantity during the tests corresponded to an output of 1,400 H.P. As the air temperature was about 40°C. and a back pressure of 0·5 Kg. per square centimetre abs. was obtained, this result is slightly better than that given in the table of data above.

The results of tests with a condenser locomotive in actual service, including fuel consumption, are given in Table II:—

TABLE II.—NOTE REGARDING TESTS WITH THE ARGENTINE TURBINE LOCOMOTIVE.

In the table below, the figures of oil and water consumption, air temperature and vacuum are given for the official journeys with the Argentine turbine locomotive in all cases between Tucumán and Santa Fé, a distance of 797 Km. (500 miles).

Journey.	Date 1926.	Mean air temperature in the sun.	Mean air temperature in the shade.	Vacuum per cent. max.	Vacuum per cent. min.	Oil consumption litres per 1,000 ton-Km.	Water consumption litres per hour.	Average train weight tons.
1	23-25 Mar.	35°C.	27°C.	68·7	62	10·37	200	920
2	13-15 June	28°C.	19°C.	78·2	68·7	11·92	210	920
3	17-19 Sept.	30°C.	18°C	72·7	64·6	8 5	190	1,600
4	23-25 Nov.	37°C.	30°C.	68·6	61·9	10 8	210	1,320

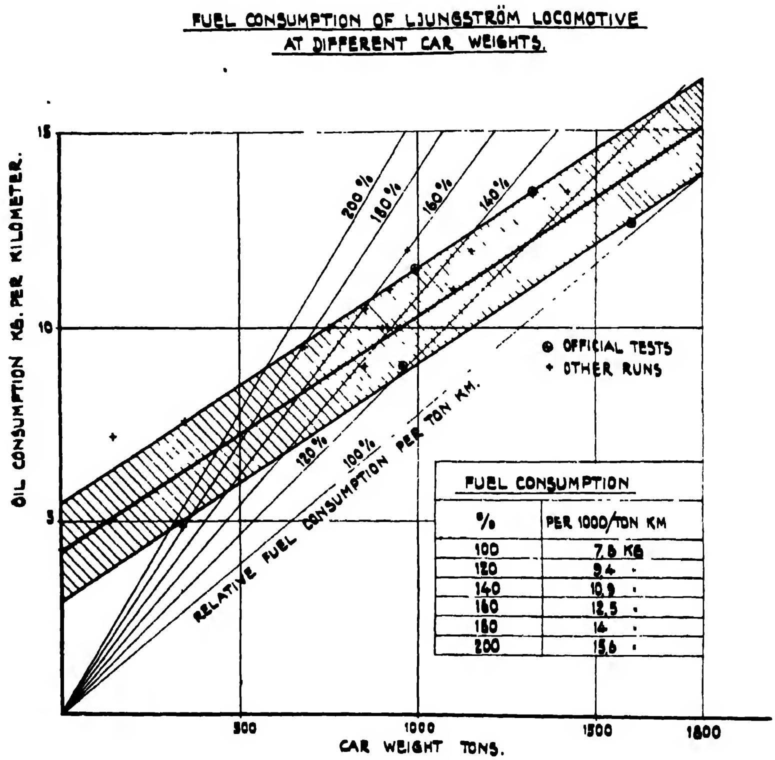


Fig. 10.

In Fig. 10 the fuel consumption for this locomotive is shown as a function of the car weight of the train. The shaded area indicates the distribution of the test points, which show a variation of about ± 12 per cent. for the average train weight. This variation includes different conditions of the road and different weather conditions such as air temperature, wind, etc., different speeds and grades, and

different handling of the engine by ten crews. Considering these circumstances, the variation seems very small indeed.

The diagram also gives an idea of the consumption per ton-Km. in relation to the optimum value. This is indicated by the bundle of beams radiating from the origin, each beam representing a constant consumption per ton-Km. The consumption figures vary practically along a straight line.

Similar diagrams have previously been given by Willan for the steam consumption of turbines and by Parsons for the coal consumption of power stations, and it is quite interesting to see that this simple law is also valid for the fuel consumption of locomotives.

The diagram also shows the great influence of the car weight on coal consumption. Taking a weight of 1,600 tons, the consumption varies between 8 and 9·5 Kg. per 1,000 ton-Km. The corresponding figures for a 300-ton train are 19 and 24·5 Kg. Thus the best figure for a 300-ton train is twice the highest figure for the 1,600-ton train.

ZUSAMMENFASSUNG

Es wird im allgemeinen angenommen, dass direkte luftgekühlte Kondensatoren von grossem Fassungsvermögen infolge der Beschränktheit des verfügbaren Raumes für Lokomotiven nicht gebaut werden können.

Der Verfasser schildert die Ergebnisse von Versuchen, die kürzlich mit einer mit Kondensatoren versehenen Dienstlokomotive vorgenommen wurden.

THE PRINCIPLES OF FLAME RADIATION

SWEDISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

T. LINDMARK

Paper No. J16

CONTENTS

Gas and flame radiation are attracting increased attention within both the metallurgical industry and steam boiler science. While gas radiation at present, through the works of Schack[1] and others, may be said to have been made comparatively clear, the question of flame radiation, if it be desired to treat this question numerically for different prevailing conditions, has not yet been fully explained.

During the past year the writer has had occasion to study flame radiation in connection with the question of heat transmission in radiation steam boilers. The transmission of heat comprises convection, gas radiation and flame radiation, and the latter constitutes by far the greater part of the transmission.

Flame radiation consists partly of chemical radiation and partly of radiation from the extremely small particles of carbon which arise when the hydrocarbons are cracked. Very little research work appears to have been done with regard to the chemical radiation, and in the following it will not be taken into consideration in other respects than that it will be included in the radiation from the above-mentioned, finely divided particles of carbon.

The fuel generally used in such radiation steam boilers is oil or pulverised coal. If oil is used, it is fed through a burner, which breaks it up into very small particles. The small drops of oil vaporise very quickly in the combustion chamber of the boiler,

[1] See, for instance: A. Schack, Über die Strahlung der Feuergase und ihre praktische Berechnung. Zeitschr. für techn. Physik. Jubileumsheft, 1924, No. 6.

forming hydrocarbons which in turn, at the correspondingly higher temperature, are decomposed into carbon and hydrogen. In combustion with the oxygen of the air the carbon forms carbon dioxide and the hydrogen forms water vapour. The rate at which the combustion takes place is dependent on the degree of turbulence or, as it may also be expressed, on the more or less intimate mixing of the combustion air with the drops of oil, or with the decomposed carbon and hydrogen, respectively. In this connection it may be taken for granted that the combustion of the hydrogen takes place much faster than that of the carbon.

The finely-divided particles of carbon obtained in the above-mentioned decomposition in all probability form a spherical complex in place of the former drop of oil. The size of these extremely small particles of carbon exercises a great influence on the flame radiation, and this influence will be referred to later.

If pulverised coal is used, the course of events will be different. The particles of coal, which consist of carbon, ash and volatile constituents, vaporise at a certain temperature, the volatile constituents forming a cloud around the coal core. When the temperature is increased further, the hydrocarbons of the volatile constituents are decomposed into carbon and hydrogen, and the core of coked coal will be surrounded by a number of extremely small particles of carbon, together with hydrogen and water vapour. In the same way as in the case of oil fuel the particles will then burn, forming carbon-dioxide and the hydrogen forming water vapour.

Primarily it may be assumed that the above-mentioned, extremely small particles of carbon are of about the same size as those which arise when oil fuel is used. Future experiments will probably throw more light on this question. The number of carbon particles in this case is, however, considerably less, counting for a certain number of fuel calories, this being due to the fact that the above-mentioned core of coal (of coke) constitutes a considerable portion of the fuel. Inasmuch as the radiation from a flame is dependent on the number of radiating particles of carbon and the size of these particles, the radiation from a pulverised-coal flame should thus be considerably less than that from an oil flame. Although the writer is unable, at present, to submit any comparison founded on experiments between the extent of the radiation from an oil flame and that from a pulverised-coal flame, experience gained in tests with steam boilers seems to indicate a smaller difference between the radiation in the case of these two fuels than would, theoretically, be expected.

This seeming lack of correspondence between theory and reality may possibly be explained by some factor which exercises a favourable influence on the transmission of heat in the case of a pulverised-coal flame. The fact is that the above-mentioned coal core has proved to increase in volume during the vaporisation. This increase of the volume is quite natural, inasmuch as the vaporisation takes place from all parts of the carbon particle, and the gases, consequently, must break through the coal core in all directions. When the gases have left the coal, there remains a very porous and "inflated" core of coke, which is built up principally of "membranes" and "lattices." The structure of this coke core facilitates its comparatively rapid combustion, and the increase in the volume of the coke core increases the part played by this core in the total radiation. Of course, the decrease in the absorption coefficient of the coke core simultaneously with the increase in the volume of the latter must be taken into consideration.

H. E. Newall and F. S. Sinnatt[2] have studied this increase of the volume and have found it in some cases to be as high as eightfold (Vitrain 800°C.)[3].

[2] The Combustion of Particles of Coal in Air. The study of Cenospheres II. H. E. Newall and F. S. Sinnatt. Fuel, 1928, page 335.

[3] The writers who have treated the question of flame radiation have worked on assumptions that are, in part, considerably simplified. Thus, A. Schack (Strahlung von leuchtenden Flammen. Z. techn. Phys. 1925, page 530) assumes that the flame is of the same character as a solid body, although with a much smaller absorption coefficient. W. J. Wohlenberg and D. G. Morrow (Radiation in the Pulverised Fuel Furnace, American Society of Mechanical Engineers, 1925, page 127) take the radiation from the carbon particles for granted but assume these particles to have the same size that they obtain in the pulverisation process, with the reduction in volume that arises through the vaporising of the hydrocarbons. Wohlenberg and Morrow thus base the radiation on the radiation of the coke cores and do not take into consideration either the decomposition of the hydrocarbons or the swelling of the coke cores. The figures that they arrive at for the radiation of a pulverised coal flame are, therefore, too small. Broido (American Society of Mechanical Engineers, 1925, page 1131) questions the correctness of the assumption, made by Wohlenberg and Morrow, that the degree of pulverisation is the deciding factor with regard to the radiation. There is no doubt but that the degree of pulverisation exercises a certain influence, but this influence is reduced by the, probably, relatively constant dimensions which the carbon particles obtain in the decomposition of the hydrocarbons. Wohlenberg and Morrow have not touched on the problem of the radiation of an oil flame, nor can this problem be solved by their methods.

Together with H. Edenholm, the writer has published a treatise on this subject (The Flame Radiation in Water-cooled Furnaces, Publications of Ingenjörsvetenskapsakademien—The Royal Swedish Institute for Scientific Industrial Research—No. 66, Stockholm, 1927), in which the oil-flame radiation is treated on the basis of the radiation from the extremely small particles of carbon which arise when the hydrocarbons are decomposed. The treatise also covers a series of experiments which confirm the theory.

The starting point when calculating the flame radiation is the formula:

$$W = (C\phi)_{\text{flames}} \cdot F \left[\left(\frac{T_g}{100} \right)^4 - \left(\frac{T_w}{100} \right)^4 \right];$$

in which C = the radiation constant
ϕ = the angular coefficient.
F = the surface subjected to radiation,
T_g = the average temperature of the flame,
T_w = the ,, ,, ,, surface.

The angular coefficient ϕ is the most important factor in this formula. It is possible to calculate this coefficient by assuming the carbon particles to have a constant magnitude and to be evenly distributed in a semi-spherical space. Under these conditions the following formula will be obtained:[4]

$$\phi = 1 - e^{-\frac{3}{4} \cdot \frac{v}{V} \cdot \frac{R}{r}}$$

in which v = the volume of carbon,
V = the volume of gas,
R = the radius of the hemisphere,
r = the radius of the carbon particle.

This theory has, in so far as it refers to the radiation of an oil flame, been verified by experimental work in the steam-technical laboratory of Tekniska Högskolan (The Stockholm Technical University).

With regard to the apparatus used in these experiments and the manner in which they were performed, reference is made to the previously-mentioned treatise by T. Lindmark and H. Edenholm.

The results comprise convection, gas radiation and flame radiation (which in this case is assumed to cover also the chemical radiation). The convection is calculated according to the formula of Jürges and Nusselt, and the gas radiation in accordance with the investigations of Schack, brought together in the ordinary radiation formula:

$$(C\phi)_{\text{gas}} \cdot F \cdot \left[\left(\frac{T_g}{100} \right)^4 - \left(\frac{T_w}{100} \right)^4 \right];$$

in which the product $(C\phi)_{\text{gas}}$ is not constant but variable and a function of the temperature of the gas and the air constants.

When the convection had been deducted from the total heat transmission arrived at, the remainder was, consequently, the gas

[4] See T. Lindmark and H. Edenholm, treatise previously mentioned, p. 11.

radiation and the flame radiation, the total value of which could be expressed by the formula:

$$(C\phi)_{total} \cdot F \cdot \left[\left(\frac{T_g}{100}\right)^4 - \left(\frac{T_w}{100}\right)^4\right];$$

$(C\phi)_{gas}$ is calculated for the gas temperature and the air constants with regard to the results of Schack's experiments and $(C\phi)_{flames}$ is calculated by means of the relation:

$$(C\phi)_{flames} = \frac{(C\phi)_{total} - (C\phi)_{gas}}{1 - \frac{(C\phi)_{gas}}{C_{flames}}}$$

The radiation constant C_{flames} cannot be assumed to be equal to the value for a black body, inasmuch as the finely broken-up carbon particles are, to a certain extent, transparent and the number of particles which are passed by a ray is limited. In the investigations mentioned above the probable figures for C_{flames} was found to be 90 per cent. of the value for a black body.

The figures for ϕ_{flames} which were obtained as a result of the above-mentioned calculations are so high that they can only be explained by assuming the size of the carbon particles, reduced to constant dimensions and an even distribution in the space, to be of the magnitude 0—2μ, and, consequently, in volume only 1 1000, or less, of the size of the particles obtained when pulverising the coal.

It is only recently that research work regarding the radiation of pulverised-coal flames has been taken up in the steam-technical laboratory of Tekniska Högskolan (The Stockholm Technical University). The results that are arrived at in these tests will probably be of importance in the series of problems which demand solution in connection with the details of construction of radiation steam boilers.

ZUSAMMENFASSUNG

Gas- und Flammenstrahlung lenken wachsende Aufmerksamkeit auf sich, aber wahrend das Problem der Gasstrahlung verhaltnismassig klar ist, ist die Frage der Flammenstrahlung noch nicht voll geklärt

Der Verfasser hat kürzlich die Flammenstrahlung im Zusammenhang mit dem Wärmeübergang in Strahlungsdampfkesseln studiert. Der Wärmeübergang umfasst Konvektion, Gasstrahlung und Flammenstrahlung, wobei letztere den weitaus grössten Anteil am Übergang darstellt. In Strahlungsdampfkesseln wird meist Öl oder Staubbrennstoff verfeuert. Von diesen beiden handelt der Bericht. Der Verfasser verweist auch auf die wichtigen Forschungen, die gegenwärtig über die Flammenstrahlung der Staubbrennstoffe in den Laboratorien der Technischen Hochschule Stockholm angestellt werden.

DU RÔLE DES TECHNICIENS ET DE CE QUE DOIT ÊTRE L'ÉDUCATION DES CHAUFFEURS

(THE DUTY OF THE FUEL TECHNOLOGIST AND THE TRAINING OF THE STOKER)

BELGIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

F. SMAL

Paper No. J17

CONTENTS

INTRODUCTION

Depuis l'apparition de la machine à vapeur, voilà près d'un siècle et quart, l'abaissement du prix de revient de la calorie a fait l'objet de recherches incessantes auxquelles ont participé les chercheurs de tous les pays. Des études ont été faites en vue de déterminer les dimensions les plus judicieuses des foyers, telles celles de Wye Williams consécutives aux célèbres expériences de Davy sur l'impossibilité de rallumer, une fois produit au foyer, le noir de fumée.

Des initiatives furent prises, en Belgique, il y a plus de deux tiers de siècle, par des chauffeurs d'élite qui, alimentant des foyers de locomotives au moyen de gros coke et de gailletteries, envisagèrent de réduire les pertes d'imbrûlés par les escarbilles en diminuant de plus en plus les interstices régnant entre les barreaux des grilles; cette pratique amena indirectement la disposition des foyers de locomotives Belpaire à grandes surfaces qui permit l'emploi des combustibles menus de faible valeur relative. Le développement

toujours croissant du volume des chaudières à vapeur et des fours, de même que la construction rationnelle de l'enveloppe des foyers, ont réduit à peu de chose les pertes de chaleur par rayonnement. Enfin, entre mille autres perfectionnements, l'application du principe de la récupération de la chaleur sensible des fumées perdues, dans les chaudières à vapeur, par des économiseurs, et, dans les fours, par des chambres de récupération, ont élargi toujours plus les possibilités économiques ou techniques de l'ingénieur.

Tous ces perfectionnements se rapportent, bien entendu, au chauffage direct sur grille, à l'exclusion du chauffage au gaz, dont on ne s'occupe pas dans cette note, et qui a donné lieu, en plus, à des progrès importants particuliers aux températures élevées.

Cependant l'évolution est lente, en ce qui regarde le travail proprement dit du chauffage sur grille effectué par l'ouvrier chauffeur.

C'est que, pendant bien longtemps, la conduite des feux a été laissée à l'unique initiative du chauffeur auquel on attribuait des "qualités sportives" portant sur la façon de confectionner le feu. D'ailleurs, par l'organisation de concours de chauffeurs, on voulait mettre en lumière ces qualités sportives qui se manifestaient, sans contredit, dans une certaine mesure, mais qui cependant ne prouvaient pas toujours que les lauréats de ces concours pouvaient assurer par leur travail des conditions économiques régulièrement optima. Quoi qu'il en soit, dès l'apparition de la calorimétrie, les techniciens ont toujours pu définir ce que devait être la conduite rationnelle des feux. Toutefois, dans celle-ci, jouent tant de variables indépendantes, que sa réalisation pratique a été longtemps un "à peu près" assez grossier et qu'il était commode de penser que le chauffeur pouvait posséder des facultés spéciales de perception lui permettant de régler au mieux les phénomènes thermochimiques que seules, cependant, des analyses précises pouvaient régler. Car enfin, si exercé que soit l'œil du chauffeur, peut-il fixer le point de naissance de l'oxyde de carbone dans la flamme ou, ce qui serait plus extraordinaire encore, l'apparition de l'air en superexcès dans cette même flamme? Le chauffeur ne le peut évidemment pas.

Aussi, il y a déjà bien des années que des efforts sont faits pour pourvoir le chauffeur d'appareils indicateurs de certaines grandeurs se rapportant au *tirage* ou bien encore à la *composition chimique des fumées*, mais il semble bien que jusqu'ici on n'ait réussi qu'à encombrer les chaufferies d'appareils nombreux, particulièrement enregistreurs, et dont on ne peut généralement pas interpréter les indications, soit que ces appareils soient d'un modèle trop réduit,

soit que leurs indications soient tardives, soit que leur fonctionnement soit délicat.

En conclusion, le chauffeur, dont l'art consiste à mettre en œuvre les procédés manuels indispensables au bon entretien des feux et de la chaufferie, réclame le concours du technicien qui doit, par des opérations de réglage déterminées, donner au chauffeur toutes indications précises pour la conduite des feux. Le but de cette communication sera de préciser le rôle du technicien et de montrer ce que doit être le travail du chauffeur.

Le principe de la méthode a déjà fait l'objet d'une communication au Congrès du Chauffage Industriel de Paris en 1923,[1] cette communication groupant dans ses grandes lignes, le résultat de travaux publiés dans les Annales des Mines de Belgique[2] et la Revue Universelle des Mines[3] touchant le réglage des feux.

Nous exposons ici quelques considérations complémentaires touchant la marche des fourneaux pour mieux faire ressortir l'exiguïté du cadre dans lequel doivent rester enfermées les indications d'appareils enregistreurs donnant la mesure des dépressions différentielles ou simples en un point du fourneau.

Du Fonctionnement des Fourneaux

La mesure des dépressions ne peut à elle seule servir de guide au chauffeur pour la conduite économique des feux, en raison de la nature complexe des facteurs qui déterminent le "*tirage.*"

On appelle "tirage" le poids des gaz débités dans l'unité de temps par le *fourneau*. Anatomiquement, le "fourneau" comprend le cendrier, la grille, le foyer, les carneaux, le registre et la cheminée. Les facteurs qui déterminent le tirage sont la "*dépression*" et les "*résistances du fourneau*." La "dépression" mesure la force motrice provoquant l'appel de l'air dans le foyer et la circulation des fumées dans le fourneau, tandis que les "résistances du fourneau" proviennent du frottement des molécules gazeuses entre elles et sur les parois du fourneau, de la résistance de la grille, de la couche des cendres provenant des combustions antérieures et de la couche de charbon en ignition, elles proviennent aussi des coudes simples ou doubles, des changements de section des carneaux et enfin du *registre*.

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[1] V. Chaleur et Industrie Juillet 1923 Comptes Rendus du Congrès du Chauffage Industriel p. 2‚2.

[2] Annales des Mines de Belgique 1922 t. XXIII 3e et 4e Livraisons p. 699 et 935. Etude sur le chauffage direct.

[3] Revue Universelle des Mines 1er juin 1923. Concours de chauffeurs.

Le *registre* est un écran mobile ou guichet qui a pour mission de régler la vitesse d'écoulement des fumées dans le fourneau et d'arrêter la combustion. Cet organe est le plus important du fourneau, étant entendu que le point capital pour l'industriel est d'obtenir, avant tout, la quantité variable de chaleur nécessaire à ses opérations. Le registre détermine donc les différents régimes de marche du fourneau, mais sans aucune liaison obligée avec le caractère économique de la combustion.

THÉORIE DU REGISTRE

On exprime la dépression, les résistances du fourneau, ainsi que l'action du registre, en millimètres de colonne d'eau.

Pour étudier l'action du registre, on ramène celui-ci à un guichet placé dans un courant gazeux s'écoulant d'une manière permanente par un orifice percé dans un réservoir.

Cette étude se fait en appliquant la formule de Daniel Bernouilli modifiée pour un gaz pesant à température constante:

$$Z - \frac{V^2}{2g} - 8.000\ \frac{1 + a\,\theta}{\delta}\ l.\,p = \text{Constante}$$

où

Z, représente la distance verticale d'un point de la trajectoire au-dessus d'un plan horizontal de comparaison.

V, la vitesse du courant, en mètres par seconde, dans l'orifice.

g, la gravité en mètres par seconde-carré.

a, le coefficient de dilatation des gaz.

θ, la température du gaz.

δ, la densité du gaz par rapport à l'air.

p, la pression statique au point considéré en kg m².

8.000, la hauteur en mètres de la couche d'air atmosphérique supposé à la densité uniforme de 1,293.

Le réservoir sera ici la partie du fourneau à l'amont du registre et l'orifice, la section rendue libre par le registre.

La vitesse du gaz dans le fourneau, c'est-à-dire dans le réservoir, sera exprimée par $V_R = \gamma\, m\, V$

où

m, est le rapport de la section du réservoir, normale à la direction du courant, à la section de l'orifice.

γ, le coefficient de contraction de la veine qui s'écoule par l'orifice.

On pourra écrire pour une même trajectoire étant entendu que

p, désigne la pression statique du gaz dans la veine fluide qui s'écoule, et

p_R, la pression statique du gaz dans le réservoir:

$$Z - \frac{V^2}{2g} - 8.000\,\frac{1+\alpha\,\theta}{\delta}\,l.\,p = \text{Constante}$$

$$Z_R - \frac{V_R^2}{2g} - 8.000\,\frac{1+\alpha\,\theta}{\delta_R}\,l.\,p_R = Z_R - \frac{\gamma^2\,m^2\,V^2}{2g} - 8.000\,\frac{1+\alpha\,\theta}{\delta}\,l.\,p_R$$

car δ_R est peu différent de δ et peut être remplacé par cette grandeur. En soustrayant les deux expressions membre à membre, il viendra:

$$Z - Z_R - V^2 \cdot \frac{1-\gamma^2\,m^2}{2g} + 8.000\,\frac{1+\alpha\,\theta}{\delta}\,l.\,\frac{p_R}{p} = 0$$

et, en envisageant une trajectoire horizontale des molécules pour avoir $Z = Z_R$:

$$\frac{1-\gamma^2\,m^2}{2g}\,V^2 = 8.000\,\frac{1+\alpha\,\theta}{\delta}\,l.\,\frac{p_R}{p} = 16.000\,\frac{1+\alpha\,\theta}{\delta}\cdot\frac{p_R-p}{p_R+p} \qquad (1)$$

étant acquis que $l.\,\frac{p_R}{p}$ peut très approximativement s'écrire $2\,\frac{p_R-p}{p_R+p}$ à cause de la différence minime qu'il y a entre p_R et p.[*4]

Cela posé, on exprimera la perte de charge due au mouvement permanent d'un gaz dans une conduite, dans l'hypothèse d'une vitesse d'écoulement constante $\gamma\,m\,V$ et d'une pression statique variant faiblement, par la relation

$$h = p_1 - p_2 = k.L\,\gamma^2\,m^2\,V^2 \qquad (2)$$

s'appliquant à une portion de conduite de L mètres de longueur, la pression en amont de cette portion étant p_1 et celle en aval p_2 kg/m^2; k est un coefficient dépendant des constantes de la conduite.

La perte de charge, h, équivaut à une chute de pression, $p_1 - p_2$; elle s'exprime en kg/m^2 et peut se mesurer en millimètres de colonne d'eau.

Ce préambule établi, on peut appliquer ces formules au cas d'un fourneau, quel qu'il soit, en faisant les hypothèses suivantes:

(1°) invariabilité du combustible et du travail du chauffeur.

(2°) les résistances à la circulation des gaz, en dehors du registre, varieront proportionnellement aux carrés des vitesses du courant. Ces résistances ont été définies plus haut.

(3°) la vitesse du courant gazeux dans le fourneau, du cendrier au registre, est supposée *uniforme*, ce qui entraine la constance du rapport de la section des carneaux au binôme de dilatation des gaz.

*4 V. M. Bresse. Cours de Mécanique appliquée, 2e partie 1878. Paris—Gauthier Villars.

4°) après avoir franchi le registre, les gaz sont appelés dans un réservoir infini où règne, quel que soit le débit, une pression statique constante. Cette dernière hypothèse qui est très admissible dans le cas de plusieurs fourneaux branchés sur un carneau collecteur unique se rendant à la cheminée, conduit à des conclusions vraies, à fortiori, lorsque la cheminée n'active qu'un seul fourneau, l'action du registre étant dans ce cas renforcée.

(5°) le fourneau en activité ne sera assimilable à une conduite de section régulière qu'après que l'on aura converti, au point de vue des résistances, les coudes, les retours et changements de section des carneaux, la grille et sa charge (charbon et cendres) en longueurs L mètres de fourneau, la longueur du fourneau étant comprise du cendrier au registre.

Si s représente ce nombre de longueurs, le fourneau sera assimilable à une conduite de $s.\,L$ mètres.

Pour chiffrer l'influence de la position du registre, il faudra admettre non seulement la constance de k, mais aussi de s et pour cela il faudra supposer que le fourneau, la grille et sa charge seront dans le même état quelle que soit la position du registre.

Soient donc:

p_a, la pression atmosphérique en kg/m².

p_c, la pression statique en aval du registre en kg/m².

γ et m, les coefficients définis plus haut.

V_x, la vitesse des fumées, en mètres, dans la veine contractée par l'effet de la position du registre; cette grandeur est inconnue.

$\gamma\, m\, V_1$, en mètres, la vitesse de circulation des fumées dans le fourneau.

p_1, la pression, en kg m², immédiatement à l'amont du registre et qui est inconnue également.

La formule (2) s'écrira, en remplaçant p_1 par p_a et p_2 par p_1:

$$p_a - p_1 = k.s.L\, \gamma^2 m^2 V_1^2$$

ou $p_1 = p_a - k.s.L\, \gamma^2 m^2 V_1^2$

et comme dans la relation (1) $p_R = p_1$ et $p = p_c$ cette dernière relation s'écrira, puisqu'ici $\delta = 1$:

$$\frac{1-\gamma^2 m^2}{2g} V_x^2 = 16.000\,(1 + a\,\theta)\,\frac{p_a - p_c - k\,s\,L\,\gamma^2 m^2 V_1^2}{p_a + p_c - k\,s\,L\,\gamma^2 m^2 V_1^2}$$

d'où l'on tire, en posant:

$$p_a - p_c = H$$

$$32.000\, g\, k\, s\, L = A$$

$$\frac{\gamma^2 m^2}{1-\gamma^2 m^2} = \sigma \text{ et } \gamma^2 m^2 = \frac{\sigma}{1+\sigma}$$

$$V_1^2 = \frac{[p_a+p_c+A(1+\alpha\theta)\sigma] \pm \sqrt{[p_a+p_c+A(1+\alpha\theta)\sigma]^2 - 4A.H(1+\alpha\theta)\sigma}}{2ksL\dfrac{\sigma}{1+\sigma}} \quad (3)$$

Il sera commode, au surplus, d'exprimer θ et γ en fonction de m; on se rapprochera des conditions de la pratique en posant, empiriquement pour un même charbon:

$$\theta = t + a\sqrt[n]{m}$$

$$\text{et } \gamma = 1 - b\sqrt{1-m}$$

où t est la température extérieure en degrés C.; a, n et b des constantes dont la grandeur est dépendante de chaque installation et du bon réglage des feux. De toute façon cependant, θ ne variera pas lorsque la vitesse de la combustion se maintiendra.

DÉTERMINATION DU COEFFICIENT k

Elle doit se faire en dehors de l'action du registre. Le foyer sera donc mis en régime de marche maximum par l'ouverture complète de la gargouille du registre. La perte de charge totale due à la circulation des fumées dans le fourneau sera donc maximum et il sera possible de la décomposer, *par expérimentation*, pour dégager la part qui revient, dans cette perte de charge, à la grille et à sa charge, aux coudes et retours pris isolément et, par différence, aux carneaux proprement dits. Ainsi qu'il a été reconnu depuis longtemps déjà (Péclet, Bède, etc.) ces pertes de charge ne sont guère susceptibles d'évaluations analytiques sérieuses, car les seules qu'il soit possible de calculer, telles que le frottement des molécules gazeuses dans les carneaux, sont insignifiantes à côté de celles, non seulement des coudes et retours, mais du feu qui sont analytiquement indéterminables. L'expérimentation sera donc bien le seul guide un peu certain.

Suivant l'hypothèse énoncée plus haut, on posera:

L, longueur totale des carneaux en mètres.

L'expression en longueurs de carneaux sera:

pour les coudes et retours	$\Sigma a\ L$
pour la grille	$g\ L$
pour la couche des cendres	$c_1\ L$
pour la couche de charbon	$c_2\ L$

De cette façon, la résistance totale du fourneau, du cendrier au registre, sera celle d'une conduite de

$$L\,(1 + \Sigma a + g + c_1 + c_2) \text{ mètres.}$$

Pour la facilité de l'écriture, on posera

$$s = 1 + \Sigma a + g + c_1 + c_2$$

Cela étant, p_a et p_c étant les pressions définies plus haut, m étant égal à l'unité de même que γ puisque le registre est entièrement levé, la formule (2) donnera

$$H = p_a - p_c = k.\, s.\, L.\, V^2$$

H, s et V seront déterminés expérimentalement, L est une constante de l'installation et on aura finalement:

$$k = \frac{H}{s\, L\, V^2}$$

Les diverses déterminations se font ainsi:

(1°) $H = p_a - p_c$, est obtenu par la mesure de la dépression simple au registre au moyen d'un déprimomètre à eau; le nombre de millimètres d'eau de la colonne d'équilibre exprime H en kg/m².

(2°) s est une somme de rapports que l'on établit en faisant la mesure directe au 1/20 millimètre près de la perte de charge ou de la dépression en différents points choisis du fourneau, d'abord immédiatement au-dessus du feu dans le foyer, ensuite, avant et après chaque coude, retour ou changement de section important, enfin, à l'endroit du registre.

Il n'est pas indifférent de faire les mesures à n'importe quel instant: immédiatement après le nettoyage de la grille, on mettra le feu en régime de marche avec le charbon d'un premier lot pesant $\frac{P}{2}$ kg., ces $\frac{P}{2}$ kg. devant être suffisants pour alimenter le foyer pendant près de 2 heures. Pendant la combustion de ce lot, un second lot de $\frac{P}{2}$ kg. de charbon aura été préparé et, dès l'enfournement de la première charge de ce second lot, on procédera à la mesure simultanée des dépressions exactement au milieu du temps de la combustion de cette charge.

Les mesures effectuées indiqueront:

h_2 mm d'eau, pour la dépression observée au foyer.

h_3 mm d'eau, pour la dépression observée à l'avant du premier coude h'_3 mm d'eau, pour la dépression observée à l'arrière du deuxième coude	1er retour
h_4 mm d'eau, pour la dépression observée à l'avant du 3e coude h'_4 mm d'eau, pour la dépression observée à l'arrière du 4e coude.	2e retour

etc. . . . (si les coudes sont simples, on fera la mesure en amont et en aval de chaque coude).

H mm d'eau, pour la dépression un peu à l'amont du registre.

Les constantes du fourneau sont, d'autre part:

l_1 mètres, longueur du carneau, du foyer au premier coude.

l'_1 mètres, le développement moyen du premier retour.

l_2 mètres, la longueur du carneau du deuxième au troisième coude.

l'_2 mètres, le développement moyen du deuxième retour etc. ..... (si les coudes sont simples, évaluer le développement moyen d'un coude).

l_n mètres, la longueur du carneau qui s'étend du dernier coude au registre. On aura:

$$L \text{ mètres} = (l_1 + l'_1 + l_2 + l' + \ldots + l_n) \text{ mètres.}$$

Il viendra successivement:

$(h_3 - h_2)$ mm = dépression ou perte de charge due à la longueur du carneau l_1

$(h_4 - h'_3)$ mm = dépression ou perte de charge due à la longueur du carneau l_2

$(H - h_n)$ mm = dépression ou perte de charge due à la longueur du carneau l_n

et par conséquent la perte de charge h_l, due au développement total des carneaux L mètres:

$$h_l = \left\{ (h_3 - h_2) + (h_4 - h'_3) + \ldots + (H - h_n) \right\} \frac{L}{l_1 + l_2 + \ldots + l_n}$$

$$\text{d'où } s = \frac{H}{h}$$

$$\text{et } g + c_1 + c_2 = \frac{h_2}{h}$$

de même que $\Sigma a = s - (1 + g + c_1 + c_2)$.

(3°) La détermination expérimentale de V s'effectue en recherchant le nombre de kilogrammes d'air entraînés dans le foyer par kilogramme de charbon sec d'expérience. On aura prélevé au cours de la combustion des deux lots de charbon pesant $\frac{P}{2}$ kilogrammes chacun, des échantillons de gaz pour déterminer leur composition volumétrique en CO_2, CO et O_2. Un échantillon du charbon aura aussi été prélevé et soumis à l'analyse élémentaire. Les températures, à l'endroit du registre, auront été mesurées, ce qui fera connaître en fin de compte le débit du fourneau pendant l'expérience, et partant, la vitesse moyenne des fumées dans les carneaux.

Comme variante, s'il était possible d'installer dans la gargouille du registre un diaphragme à section carrée ou circulaire, l'emploi du tube de Pitot serait d'application pour la détermination directe de V.

(4°) Deux ou plusieurs expériences permettront d'obtenir une valeur moyenne de k.

PREMIÈRES CONCLUSIONS

(1°) La vitesse de la combustion dépend évidemment de la position du registre dans la gargouille d'évacuation des fumées; les relations qui précèdent établissent analytiquement la dépendance de la vitesse de la combustion et de la grandeur, m, déterminante de la position du registre.

(2°) La dépression en aval du registre est presqu'invariable dans le cas particulier où la cheminée active plusieurs fourneaux branchés sur un collecteur unique des fumées. S'il n'y a qu'un seul fourneau, la dépression motrice variera avec θ', température moyenne des fumées dans la cheminée, comme l'indique la relation

$$H = L' \times 1,3 \times \frac{273\,(\theta' - t)}{(273 + \theta')\,(273 + t)}$$

L' étant la hauteur de la cheminée et t, la température extérieure, mais dans les limites où varie θ' la puissance d'appel de la cheminée ne varie pas beaucoup encore que ces variations accentuent l'action du registre et renforcent les présentes conclusions.

(3°) La longueur fictive $s.\,L$ du fourneau comprend la longueur fictive $s_1\,L$ relative à la grille et à sa charge et la longueur fictive $s_2\,L$ relative à celle des carneaux, des coudes, des retours et changements de section. On pourra écrire $s_1 = g + c_1 + c_2$ et $s_2 = 1 + \Sigma a$; on aura successivement, si h_1 est la dépression en amont du registre et h_2 celle au foyer:

$$h_1 = p_a - p_r = k.\,s.\,L.\,V_1^2$$

et $$h_2 = p_a - p_2 = k\,s_1\,L.\,V_1^2 = k.\beta.\,s\,L.\,V_1^2$$

en posant $s_1 = \beta.\,s$ avec $\beta = \dfrac{g + c_1 + c_2}{1 + \Sigma a + g + c_1 + c_2}$ = Constante

on voit que les dépressions h_1 et h_2 varient avec m; de même on a :

$$\frac{h_1}{h_2} = \frac{s}{s_1} = \frac{1}{\beta} = \text{Constante}$$

ce qui montre que h_1 et h_2 varient dans le même sens que m.

Étude de la Variation des Dépressions dans le Fourneau

En réalité, les coefficients Σa, g, c_1 et c_2 varient sensiblement, contrairement à l'hypothèse faite, de même que le coefficient k.

k, Σa et g varient lentement avec l'état d'encrassement du fourneau et les crevasses dans la maçonnerie; la grille est brûlée petit à petit, par l'action du feu elle s'oxyde et offre de moins en moins de vides au passage de l'air.

c_2 varie très sensiblement dans le temps de la combustion de la charge et aussi avec l'allure, avec la nature physique et la qualité agglutinante du charbon.

c_1 dépend de l'allure, de la quantité des cendres et de leur fusibilité en même temps que de la longueur de la période d'activité des feux comprise entre deux nettoyages de la grille.

On peut donc dire qu'au point de vue du contrôle de la combustion, il n'y a pas de relation analytique entre la position du registre, l'allure de la combustion et les diverses dépressions dans le fourneau. *Il est toutefois essentiel de signaler qu'il y a similitude dans le sens des variations simultanées de ces diverses grandeurs et* qu'au point de vue pratique, la connaissance de la variation des diverses dépressions dans le fourneau permet de suivre la conduite des feux caractérisée en partie par la manœuvre judicieuse du registre.

Les appareils *enregistreurs* de la dépression simple, de la dépression différentielle, de même que les tachygraphes (applications du tube de Pitot) donnent des indications permanentes qui portent sur les périodes de grande activité des feux, sur celles où la combustion est moins vive, sur les temps d'arrêt prévus ou imprévus (nettoyage de la grille, accident). Leurs indications portent aussi sur des événements secondaires, tels que l'ouverture des portes du foyer pour le chargement des feux ou le "crochetage" avec ou non registre abaissé; elles portent enfin sur le percement des feux.

Le crochetage est l'opération qui consiste à rompre, au moyen du crochet à deux pointes, la croûte de coke que donnent les charbons menus agglutinants.

L'étude analytique de la variation des dépressions dans le fourneau dans les conditions idéales qui ont rendu possible la détermination de l'influence de la position du registre sera utile pour permettre l'établissement du diagramme théorique de cette variation des dépressions. Les diverses influences seront mieux dégagées et l'impossibilité de tirer de ces dépressions des indications certaines au point de vue de la conduite économique des feux apparaîtra mieux.

ÉTABLISSEMENT THÉORIQUE DU DIAGRAMME DES DÉPRESSIONS DANS LE FOURNEAU. PREMIÈRE HYPOTHÈSE

La vitesse de la combustion est maintenue constante et correspond à l'ouverture moyenne de la gargouille du registre égale à $m\Omega$, Ω étant la section totale de la gargouille. Il en résulte que le poids p kg. des fumées par kg. de combustible sec est constant et correspond à l'épaisseur des feux la plus économique déterminée par le réglage des feux.[5]

Il faut remarquer tout de suite qu'au cours de la combustion de la charge, s, variera tandis que la position du registre restera invariable; au cours d'une période comprise entre deux nettoyages de la grille, au contraire, la variation de s due à l'encrassement de la grille devra être combattue par la modification, après chaque chargement, de la position du registre.

Variations de s ; on a :

$$s = 1 + \Sigma a + g + c_1 + c_2 = \text{Constante} + c_1 + c_2$$

c_2 sera maximum et égal à c'_2 au début de la charge;
c_2 sera minimum et égal à c''_2 à la fin de la charge;
c_1 sera minimum et égal à c'_1 tout de suite après le nettoyage du feu.
c_1 sera maximum et égal à c''_1 un peu avant le nettoyage du feu.

En conséquence, l'application de la formule générale

$$h_1 = k.\ s.\ L\ \gamma^2\ m^2\ V^2$$

montre:

(1°) que *pendant la combustion d'une charge*, le registre étant invariable (m = constante) le débit varie en même temps que h_1 qui varie lui-même en même temps que c_2 ou s.

(2°) que dans les charges successives, m devra varier pour maintenir le débit *moyen* constant ($\gamma^2 m^2\ V^2$= constante) ce qui entrainera la variation continue de h_1 moyen.

On suppose θ invariable puisque l'allure est constante.

Le problème consiste à rechercher, étant donnée la valeur moyenne de m, les valeurs initiales m' et finales m'' de cette grandeur et en déduire les valeurs correspondantes h'_1 et h''_1 de même que h'_2 et h''_2 de la dépression au foyer, relatives à chaque charge.

Entre m' et m'', il y aura une série de valeurs de m, différentes pour chaque charge, et qui donneront chacune des valeurs particulières pour h_1 et h_2.

En résumé, il y a donc une double variation de h_1 et h_2 due à celle de c_1 et c_2 pendant la combustion d'une charge et à la variation de m au cours de la période comprise entre deux nettoyages successifs de la grille.

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[5] V. Annales des Mines de Belgique 1922, t. XXIII 4e livraison, page 952.

Notations

On appellera

h_1, la dépression au registre au temps milieu de la combustion de la charge.

h_2, la dépression au foyer au temps milieu de la combustion de la charge.

h'_1, la dépression au registre au début de la combustion de la charge.

h''_1, la dépression au registre à la fin de la combustion de la charge.

h'_2, la dépression au foyer au début de la combustion de la charge.

h''_2, la dépression au foyer à la fin de la combustion de la charge.

$(h_1)'$ $(h_2)'$ $(h'_1)'$ $(h''_1)'$ $(h'_2)'$ $(h''_2)'$ les grandeurs correspondantes relatives à la première charge après le nettoyage du feu.

(h_1) (h_2) (h'_1) (h''_1) (h'_2) (h''_2) les grandeurs correspondantes relatives à la charge du temps milieu de la période comprise entre deux nettoyages successifs du feu.

$(h_1)''$ $(h_2)''$ $(h'_1)''$ $(h''_1)''$ $(h'_2)''$ $(h''_2)''$ les grandeurs correspondantes relatives à la dernière charge avant le second nettoyage du feu.

On appliquera les mêmes notations en ce qui concerne s, c_1 et c_2:

$(s')'$ $(s)'$ $(s'')'$ pour la première charge.

(s') (s) (s'') charge du temps milieu.

$(s')''$ $(s)''$ $(s'')''$ dernière charge de la période comprise entre deux nettoyages successifs du feu.

Même mécanisme pour c_1 et c_2.

(*a*) *Détermination de* $(h_1)'$ *et* $(h_1)''$.

Pour la facilité de l'écriture, on appellera *période* simplement la période comprise entre deux nettoyages successifs du feu.

L'état moyen du feu au milieu de la période a donné:

$$(h_1) = k\,(s)\,L\,\gamma^2\,m^2\,V^2$$

Au début de la période on aura:

$$(h_1)' = k\,(s)'\,L\,\gamma^2\,m^2\,V^2$$

avec, par hypothèse:

$$\gamma^2\,m^2\,V^2 = \frac{(h_1)}{k\,(s)\,L} = \text{Constante}$$

$$\text{donnant } \frac{(h_1)}{(s)} = \text{Constante}$$

Comme on a $(s) = 1 + \Sigma a + g + (c_1) + (c_2)$

il viendra: $(s)' = 1 + \Sigma a + g + (c_1)' + (c_2)'$

et $(s)'' = 1 + \Sigma a + g + (c_1)'' + (c_2)''$

$$\text{or, } \frac{(h_1)}{(s)} = \text{Constante}$$

$$\text{donc } (h_1)' = \frac{(s)'}{(s)} (h_1)$$

$$\text{et } (h_1)'' = \frac{(s)''}{(s)} (h_1)$$

(*b*) *Détermination de $(h_2)'$ et de $(h_2)''$.*

$$(h_2)' = \frac{g + (c_1)' + (c_2)'}{(s)'} (h_1)'$$

$$\text{et } (h_2)'' = \frac{g + (c_1)'' + (c_2)''}{(s)''} (h_1)''$$

A chaque chargement du feu, le registre est abaissé et h_1, de même que h_2, sont nuls pendant cette opération.

L'allure étant constante, l'accroissement de c_1 est proportionnel au temps ou bien encore au nombre de charges et on pourra poser:

$$c_\tau = \mu.\ \gamma.\ m.\ V_m \tau$$

où μ est un coefficient dépendant de la teneur en cendres du combustible et de leur fusibilité et τ, le temps de marche exprimé en secondes.

(*c*) *Détermination de m' et m'', limites des variations de m pendant une période.*

On écrit:

$$(h_1)' = k\,(s)'\,L\,\gamma'^2\,m'^2\,V'^2 = k\,(s)'\,L\,\gamma^2\,m^2\,V^2$$

L'équation (1) donne

$$\frac{1 - \gamma'^2\,m'^2}{2g}\,V'^2 = 16.000\,(1 + a\,\theta)\,\frac{H - (h_1)'}{p_a + p_c - (h_1)'}$$

ou, puisque $\gamma^2\,m^2\,V^2 = \gamma'^2\,m'^2\,V'^2$

$$\frac{V'^2}{2g} = 16.000\,(1 + a\,\theta)\,\frac{H - (h_1)'}{p_a + p_c - (h_1)'} + \frac{\gamma^2\,m^2\,V^2}{2g}$$

$$\text{et finalement } \gamma'\,m' = \gamma m\,\frac{V}{V'}$$

En remplaçant γ' par sa valeur en fonction de m' on obtient une équation du 3e degré en m' que l'on peut résoudre directement ou par point.

(*d*) *Détermination de $(h_1')'$ et $(h''_1)'$, $(h'_2)'$* et *$(h''_2)'$ correspondant au début et à la fin de la combustion de la charge.*

On a:

$$(s')' = 1 + \Sigma a + g + (c_1')' + (c_2')'$$

$$\text{et} \quad (s'')' = 1 + \Sigma a + g + (c_1'')' + (c_2'')'$$

et successivement:

$$(h_1')' = k\,(s')'\,L\,\gamma'^2\,m'^2\,V_1'^2$$

$$(h_2')' = \frac{g + (c_1')' + (c_2)'}{(s')'}\,(h_1')'$$

$$(h_1'')' = k\,(s'')'\,L\,\gamma'^2\,m'^2\,V_1''^2$$

$$(h_2'')' = \frac{g + (c_1'')' + (c_2'')'}{(s'')'}\,(h'')'$$

V_1' et V_1'' se calculant par la relation (3).

(*e*) *Détermination des variations de h_1 et h_2 dues à des causes secondaires.*

S'effectue de la même manière en considérant les variations des résistances ou des valeurs de s.

Deuxième Hypothèse

La production de chaleur du fourneau doit être maximum. Le registre est entièrement levé. Pendant la période comprise entre deux nettoyages successifs des feux, l'allure ira donc continuellement en diminuant, puisqu'il ne sera plus possible de combattre l'encrassement de la grille par une plus grande ouverture de la gargouille.

Le problème consiste donc ici à rechercher la loi de variation des résistances du fourneau en fonction du temps.

Le point de départ sera.

$h_1 = H = k.\,s.\,L\,\gamma^2\,m^2\,V^2 =$ Constante

$\gamma^2\,m^2 = 1$; s et V^2 sont les variables, donc $s.\,V^2 = \frac{H}{k.\,L} =$ Constante qui est déterminée au début de la période.

On désignera par

V_τ, la vitesse moyenne des gaz (au milieu de la combustion d'une charge) après le temps τ.

$s_0 + c_\tau$, le coefficient s, après ce même temps.

On n'aura pas à tenir compte de la variation de température θ des gaz brûlés si l'on admet, ce qui se rapproche sensiblement de l'expérience, que

$$p\,(1 + a\,\theta) = \text{Constante}$$

p. étant le poids des fumées par kilogramme de charbon sec.

On aura successivement:

$$(s_0 + c_\tau)\cdot V_\tau^2 = \text{Constante et } V_\tau^2 = \frac{\text{Constante}}{s_0 + c_\tau}$$

ou $$V_\tau = \sqrt{\frac{\text{Constante}}{s_0 + c_\tau}}$$

La vitesse moyenne V_m dans l'intervalle 0 à τ

$$\text{sera } V_m = \frac{\int_0^{s+c_\tau} z\, d\, c_\tau}{c_\tau} = \frac{2\sqrt{\text{Constante}}}{\sqrt{s_o + c_\tau} + \sqrt{s_o}}$$

$$\text{or, } c_\tau = \mu \,.\, V_m \,.\, \tau = \frac{2\,\mu\,\sqrt{\text{Constante}}}{\sqrt{s_o + c_\tau} + \sqrt{s_o}} \times \tau$$

conduisant à l'équation du 3e degré

$$c_\tau^3 + 4\,\mu\, c_\tau \sqrt{s_o \times \text{Constante}} \times \tau - 4\,\mu^2 \times \text{Constante} \times \tau^2 = 0$$

En posant $M = 4\,\mu\sqrt{s_o \times \text{Constante}}$ et $N = 4\,\mu^2 \times \text{Constante}$ on obtient, tous développements effectués:

$$\sqrt[3]{\frac{N\tau^2}{2} + \sqrt{\frac{N^2\tau^4}{4} + \frac{M^3\tau^3}{27}}} + \sqrt[3]{\frac{N\tau^2}{2} - \sqrt{\frac{N^2\tau^4}{4} + \frac{M^3\tau^3}{27}}}$$

Exemples Numériques

(*a*) *Détermination de k.*—Cet exemple sera celui d'une chaudière à deux foyers intérieurs de 10 mètres environ de longueur; les fumées reviennent vers l'avant en chauffant extérieurement les parois latérales de la chaudière et gagnent la cheminée en parcourant un carneau ménagé sous la chaudière.

A chaque retour du courant, il y a deux coudes d'un développement moyen de 2,50 mètres. Il en résulte que les carneaux présentent un développement total (L mètres) de 35 mètres depuis le cendrier jusqu'au registre.

Les feux sont poussés à l'allure extrême, le registre complètement levé.

Les mesures ont donné les résultats suivants:

$$h_L = (0{,}15 + 0{,}15 + 0{,}15) \times \frac{35}{30} = 0{,}52 \text{ millimètre.}$$

Une seconde expérience ayant donné $h_L = 0{,}50$ mm, on prendra en fin de compte $h_l = 0{,}51$ millimètre

$$\text{et } s = \frac{12}{0{,}51} = 23{,}5$$

$$+ c_1 + c_2 = \frac{6,15}{0,51} = 12,1$$

$$\Sigma a = 23,5 - (1 + 12,1) = 10,4$$

L'analyse du charbon et des fumées et la mesure des températures au registre conduisent à un débit tel que—la section de la gargouille étant égale à 1/3 m²—la vitesse des gaz au registre a pu être évaluée à 5,25 mètres par seconde. Il en résulte que

$$k = \frac{h}{s.\,L.\,V^2} \quad \frac{12}{23,5 \times 35 \times 5,25 \times 5,25} \quad 0,000\,53$$

(*b*) *Influence de la position du registre.*

On aura relevé:

$$\begin{array}{lcl}
p_a & = & 10.333 \text{ kg/m}^2 \\
p_c & = & 10.321 \text{ kg/m}^2 \\
p_a + p_c & = & 20.654 \text{ kg/m}^2 \\
s & = & 23,5 \\
p_a - p_c & = & H = 12 \\
A & = & 32.000\, g\, k\, s\, L = 136.700.
\end{array}$$

D'autre part

$$\theta = 15 + 350 \sqrt{m}$$
$$\gamma = 1 - 0,1 \sqrt{1 - m}$$

Enfin le poids d'air p kg. par kilogramme de charbon sec est déterminé par la formule empirique: $p\,(1 + \alpha\,\theta) =$ constante, qui se vérifie très sensiblement pour les charbons demi-gras belges brûlés à feux réglés aux chaudières à foyers intérieurs.

L'application de la formule (3) donnera les différentes valeurs V^2 pour m successivement égal à zéro, 2/10, 4/10, 7/10 et l'unité, et, par suite, les valeurs correspondantes de $p_c = p_a - k\, s\, L\, \gamma^2\, m^2\, V^2$ ou mieux $h_1 = p_a - p_c = k\, s\, L\, \gamma^2\, m^2\, V^2$ représentant les différentes pertes de charge provoquées par le registre dans ses diverses positions.

La perte de charge au foyer s'obtiendra en multipliant h_1 par

$\frac{g + c_1 + c_2}{s} = 0,515$ et la dépression différentielle, registre-foyer,

en multipliant h_1 par le rapport $\frac{1 + \Sigma a}{s} = 0,485.$

Le tableau suivant contient tous les résultats:

Notations	Libellé	I	II	III	IV	V
m	Rapport section orifice au registre	0	0,2	0,4	0,7	1,0
θ degrés C.	Température des fumées au registre	0	250	293	335	365
γ	Coefficient de contraction des gaz au registre ...	0,900	0,910	0,922	0,945	1,000
V^2		0	251,8	138,3	57,9	27,6
V mètres	Vitesse des fumées dans l'orifice	0	15,9	11,8	7,61	5,25
$\gamma m V$ mètres	Vitesse des fumées dans le fourneau	0	2,894	4,352	5,033	5,25
p, kg. d'air	Poids d'air par kg de charbon...	0	19,5	18	16,8	16
allure kg/m²	Combustion par m² de grille	0	45,25	('8,07	78,72	82,11
H mm.	Dépression motrice totale	12	12	12	12	12
h_1 mm.	Dépression à l'amont du registre	0	3,65	8,25	11,05	12
$H-h_1$ mm.	Perte de charge due au registre	12	8,35	3,75	0,95	0
p_2 mm.	Dépression au foyer ...	0	1,90	4,25	5,70	6,15
h_1-h_2 mm.	Dépression différentielle	0	1,75	4,00	5,35	5,85

(*c*) *Etablissement théorique du diagramme des dépressions dans le fourneau* : *simple au registre, simple au foyer et différentielles.*

(*a*) *Première hypothèse.*—On partira des données numériques relatives à l'influence de la position du registre dans l'essai n° III ci-dessus pour une valeur moyenne de m = 0,4 avec k = 0,00053.

Tous calculs effectués, il est permis d'établir le diagramme théorique dans le cas de la combustion à vitesse constante (Fig. 1) suivant les valeurs de s réunies dans le tableau suivant:

	Première charge de la période.		Charge du milieu de la période.		Dernière charge de la période.	
	Commencement $(s')'$	Fin $(s'')'$	Commencement (s')	Fin (s'')	Commencement $(s')''$	Fin $(s'')''$
l	1	1	1	1	1	1
Σa	10,4	10,4	10,4	10,4	10,4	10,4
c_2	9	5	9	5	9	5
c_1	0	0,2	3	3,2	6	6,2
ε	2	2	2	2	2	2
s	22,4	18,6	25,4	21,6	28,4	24,6
	$(s)'$ = 20,5		(s) = 23,5		$(s)''$ = 26,5	

Des données complémentaires sont nécessaires pour le tracé du diagramme.

La différence entre les valeurs c_1 de la fin de la dernière charge et du commencement de la première étant 6,2, le temps de combustion proprement dit au cours de la période ayant été 3 heures 11′ ou 11.500 secondes environ, la relation

$$C_\tau = \mu \cdot \gamma m V_m \cdot \tau$$

donne : $6{,}2 = \mu \times 4{,}35 \times 11.500$

et $\mu = 0{,}000125$ ou $1/8000$

Il a été brûlé 218 kilos de charbon par mètre carré de surface de grille en 25 charges. La charge a donc été de 8,72 kilos par mètre carré et a brûlé pendant 7′ 38″.

Le temps moyen de l'opération du chargement ayant été de 52 secondes, la période de combustion comprise entre deux nettoyages successifs de la grille a donc duré 3 heures 33 minutes. Le registre ayant été manœuvré avant chaque chargement, on possède tous les éléments pour le tracé du diagramme des dépressions simples, soit au registre, soit au foyer, ou bien encore de la dépression différentielle (Fig. 1).

Le tracé du diagramme des V^2 ou des V peut également s'établir.

(β) *Deuxième hypothèse.*—On part des mêmes données générales en supposant que la chauffe s'effectue à registre entièrement levé. $\gamma^2 m^2$ sera égal à l'unité et tous calculs faits, on pourra dresser le diagramme théorique dans l'hypothèse de l'activité maximum du fourneau (Fig. 2).

Sous le bénéfice des remarques faites au précédent exemple numérique le tracé des diagrammes sera aisé en observant que le temps de combustion des charges s'allonge au fur et à mesure de l'encrassement de la grille.

Il faut noter en passant que la vitesse des fumées est passée de 5,65 mètres par seconde pendant la première heure à 4,63 mètres pendant la quatrième. Il en résulte que la vitesse de la combustion a été réduite dans l'intervalle de 18 pour cent environ.

(*d*) *Causes secondaires*:

(α) *Fermeture de la gargouille du registre.*—Lorsque le registre est abaissé, la circulation des fumées est arrêtée et les dépressions s'annulent; c'est pour cette raison qu'alors le stylet des appareils enregistreurs gagne le zéro du diagramme.

(β) *Ouverture des portes du foyer à registre ouvert* (Fig. 3).

Dans ce cas l'appel de la cheminée persiste et l'air froid pénètre par la porte dans le fourneau en même temps qu'à travers la grille et le feu.

On détermine l'orifice équivalent de la grille et du feu par la formule générale (1) s'appliquant à la dépression au foyer—on peut

déterminer la vitesse de l'air froid traversant la grille et comme on en connaît le poids et le volume, on possède l'orifice équivalent de la grille et du feu. La section des portes est connue, ce qui permet

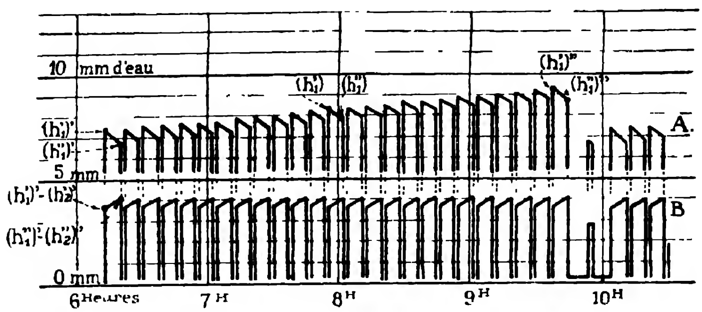

Fig1 Reglage de la combustion par le registre

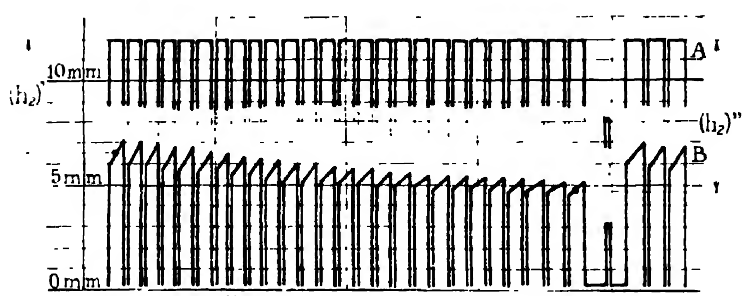

Fig2 Allure de la combustion maximum (Registre complètement levé)

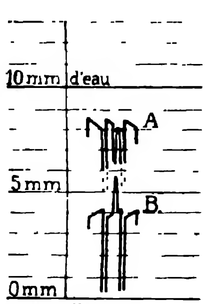

Fig3 Ouverture des portes du foyer

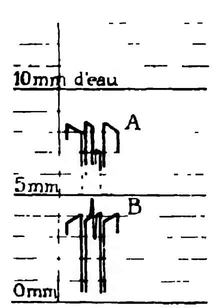

Fig4 Trouage des feux

Remarque Dans toutes les figures A se rapporte à la dépression simple et B à la dépress. différentielle

de déterminer l'afflux instantané de l'air froid dans le fourneau par la grille et le feu et par la ou les portes ouvertes.

Pour cela, on se sert de l'équation (1) pour la pénétration de l'air dans le fourneau, ensuite de l'équation (2) pour la circulation des

gaz dans le fourneau, après on établit la relation (1) pour le franchissement du registre et enfin on exprime la permanence du mouvement ou l'égalité du débit à l'entrée et à la sortie du fourneau.

Ce calcul appliqué à un cas concret démontre que la vitesse de la combustion est diminuée pendant l'ouverture des portes et que le fourneau se refroidit vite par l'afflux de l'air froid par les portes.

Lorsque la grille est petite par rapport à la section des portes, le chargement des feux à registre ouvert entraîne une perte de calories qui peut atteindre 4 à 5 pour cent du pouvoir calorifique du charbon. Ce n'est que lorsque la grille est grande que l'inconvénient s'atténue pour disparaître même si l'air froid entrant par les portes assure la fumivorité des charbons très gazeux.

Il n'en est pas moins vrai que lorsqu'un feu est bien réglé et la fumivorité rendue bonne, l'ouverture des portes à registre ouvert est une nuisance.

(γ) *Trouage des feux* (Fig. 4).—Ce phénomène se produit lorsque la charge a été mal répartie; l'air froid pénètre alors dans le foyer sans rencontrer de charbon en ignition et le résultat est le même que celui de l'ouverture des portes à registre levé. L'application de la théorie précédente à ce cas montre qu'au diagramme enregistreur la dépression simple diminuera subitement tandis que la dépression différentielle augmentera. La vitesse des fumées s'accroît subitement et produit un coup de bélier dans le carneau collecteur général, d'où choc et ralentissement consécutif du mouvement. Après le choc, le régime de la circulation se rétablit mais en fumées fortement refroidies. Après le trouage du feu, la dépression différentielle est déterminable en tenant compte de la chute de température des fumées. On trouve généralement que cette dépression est presque la même que celle avant le phénomène du trouage, si, bien entendu, la dépression dans le carneau collecteur n'a pas varié.

Réglage de la Combustion

Il est impossible de régler la combustion uniquement par l'emploi d'appareils enregistreurs de la dépression simple ou différentielle.

La méthode d'investigation décrite plus haut, appliquée à des cas concrets, permet de montrer que:

(1°) par le maintien de la valeur de la dépression simple au registre, on peut obtenir des régimes de combustion très dissemblables au cours desquels les dépressions différentielles dans chaque régime sont différentes,

(2°) par le maintien de la valeur de la dépression différentielle on peut obtenir des régimes de combustion différents pendant lesquels la dépression simple à l'endroit du registre notamment varie d'un régime à l'autre.

(3°) enfin par le maintien simultané de la dépression simple au registre et de la dépression différentielle, on aboutit à des régimes de combustion dissemblables au point de vue économique lorsque le combustible varie.

Toutes ces variations sont dues à celles de l'épaisseur du feu d'une part, et de la limite de combustibilité des divers charbons, d'autre part, ainsi qu'il a été exposé dans l'Etude sur le chauffage direct, étude parue dans les Annales des Mines de Belgique (loc. cit.).

C'est pour cette raison que la méthode à la base de la conduite économique de la combustion est celle du *Réglage des feux* adoptée par la *Commission des Economies de Combustibles* de *l'Association Belge de Standardisation*. Ceci nous conduit à définir le rôle du technicien de chaufferie, d'un côté, et du chauffeur, de l'autre.

RÔLE DU TECHNICIEN DANS LA CONDUITE DES CHAUFFERIES

Ce rôle consiste à déterminer, pour un même charbon et par l'analyse des fumées portant sur CO_2, O_2 et CO, la loi de la variation des épaisseurs du charbon sur la grille en fonction de l'allure de la combustion.

Pour cela il devra appliquer les règles pour la détermination pratique de l'épaisseur standard des feux pour deux positions extrêmes du registre dans la gargouille.[6]

Le technicien recommencera son double essai sur un échantillon de même qualité mais différemment cendreux dans le but de dégager la loi de la variation des épaisseurs du feu en fonction de la teneur en cendres du charbon.

Enfin il effectuera à nouveau une quadruple détermination de l'épaisseur standard des feux aux mêmes allures extrêmes de combustion et aux mêmes teneurs extrêmes en cendres, à un moment où l'état hygrométrique de l'air comburant sera très différent de celui pendant lequel la première série d'essai a été effectuée.

En résumé, il y a trois variables indépendantes à faire jouer, ce sont:

(1°) la vitesse de combustion ou l'allure,
(2°) la teneur en cendres du charbon étudié,
(3°) l'état hygrométrique de l'air.

[6] Annales des Mines de Belgique 1922 t.XXIII 4e livraison, p. 952.

Le tableau schématique des essais est le suivant:

(1°) Essais par journée sèche et froide:			
A.	Charbon peu cendreux	I.	allure lente.
		II.	allure vive.
B.	Charbon cendreux	III.	allure lente.
		IV.	allure vive.
(2°) Essais par journée humide et chaude:			
C.	Charbon peu cendreux	V.	allure lente.
		VI.	allure vive.
D.	Charbon cendreux	VII.	allure lente.
		VIII.	allure vive.

Ces huit essais permettent d'établir *pour cette qualité de charbon* la gamme des épaisseurs de feux qu'il y aura lieu d'adopter suivant les cas.

Lorsque le technicien aura pris l'habitude de ces essais, il pourra en effectuer quatre par journée.

Le technicien aura ensuite à rédiger les instructions aux chauffeurs selon un système de fiches sur lesquelles seront consignées toutes les précisions voulues.

Il sera renseigné chaque jour sur l'état hygrométrique de l'air par des psychromètres et le laboratoire d'incinération fournira, pour chaque lot de combustibles, la teneur en cendres du charbon. Ces deux ordres de renseignements permettront au technicien de fixer les limites entre lesquelles les épaisseurs du feu oscilleront suivant la vitesse de combustion, laquelle est essentiellement variable à tout instant.

Le chauffeur sera renseigné sur la vitesse de la combustion par un déprimomètre donnant la dépression différentielle à grande échelle; à chaque vitesse de combustion correspondra une épaisseur du feu que le chauffeur devra s'efforcer d'obtenir.

Le technicien aura enfin la charge du contrôle qui sera facile par la mesure des épaisseurs de feux réellement obtenue sur la grille pour la vitesse de combustion renseignée approximativement par le déprimomètre différentiel.

RÔLE DU CHAUFFEUR

Le rôle du chauffeur devient dès lors très confiné et en tout cas bien défini. Il portera,

(1°) sur la préparation du charbon avant la charge: éloignement des pierres, mouillage du charbon, etc.

(2°) sur les opérations du chargement du feu qui se fera en s'assurant que le niveau d'eau n'est pas trop bas; en fermant le registre

avant d'ouvrir les portes du foyer; en chargeant le feu à l'avant, au milieu et au fond de la grille, sans négliger les parties latérales; en fermant les portes du foyer avant la réouverture du registre; en consultant le manomètre et en rectifiant la position du registre pour corriger l'allure; enfin en veillant à l'alimentation.

(3°) sur la préparation et la surveillance du feu;
(4°) sur le maintien de l'épaisseur imposée du feu;
(5°) sur la conduite du feu;
(6°) sur le poids et la fréquence des charges;
(7°) sur la manœuvre du registre;
(8°) sur l'opportunité du nettoyage des feux;
(9°) sur l'opération du nettoyage des feux;
(10°) sur l'organisation des nettoyages.

Les soins du chauffeur seront aussi apportés au respect des conditions relatives à la sécurité,

(1°) en veillant au bon fonctionnement des appareils de sécurité;

(2°) en veillant au bon fonctionnement des pompes ou autres appareils servant à l'alimentation;

(3°) en procédant en temps voulu au nettoyage intérieur et extérieur des appareils de chauffe;

(4°) en suivant de près la mise à feu et hors feu des chaudières;

(5°) en veillant à la bonne conduite des réchauffeurs et surchauffeurs;

(6°) enfin en appliquant des règles générales relatives à la protection des tuyauteries contre la gelée, à la propreté dans la chaufferie, au bon entretien des maçonneries et des calorifuges et enfin en s'exerçant à tout observer sans le moindre retard.[7]

[7] Ces instructions rappelées ici en raccourci sont rassemblées dans le *Catéchisme des Chauffeurs et des Conducteurs de machines* rédigé sous les auspices de l'Association des Ingénieurs sortis de l'Ecole de Liége, 9e édition, Liége, Imprimerie Vaillant-Carmanne.

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LIST OF EXPERTS

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RÉSUMÉ

Until recently it was commonly accepted that stokers had acquired a special ability for the working of furnaces due to long years of experience. Without contesting this it is, however, necessary to stress the fact that normal conditions of combustion must be based upon suitable damper regulations and gas analyses. These analyses represent the conditions of the fire due to the thickness of the fuel bed on the grate.

For a number of years the control of combustion has been based on conditions of draught within the combustion chamber, or on the differential partial vacuum between two points in the furnace before the damper. It is understood that the expression "furnace" includes the grate, the combustion chamber, the ashpit, the flues, the damper and the chimney. This method, however, is not perfect, in view of the fact that it does not take into consideration the chemical composition of the waste gases This damper theory, which is comparatively new, indicates that the vacuum or the amount of air supplied to the furnace per unit of weight of dry coal depends on a number of independent variables, which are difficult to incorporate into definite formulae. These variables depend on the condition of the fire, and also on the degree of air-tightness of the furnace, as well as on the rate of combustion, the ash content and its fusibility, the degree of resistance of the air through the fuel bed, the humidity of the air, and the capability of the stoker. The efficiency of the furnace has been investigated with varying conditions of one of the variables, the others remaining constant, in order to determine in each case the most suitable thickness of the fuel on the grate. This research work is the duty of the fuel technologist, whose findings will supply the stoker with the most suitable conditions of firing in order to get the best results for each type of fuel.

The stoker's work must consist chiefly in keeping normal firing conditions such as correct depth of fuel bed, speed of combustion and cleanliness of the fire to obtain the highest efficiency of the furnace.

The limited space permitted has not given an opportunity to enlarge upon the subject to the Conference, as would have been desirable, but it has been possible to discuss the main points of this subject and refer to publications in connection with this problem.

GENERAL REPORT ON SECTION J

UTILISATION OF FUELS FOR STEAM GENERATION AND THE PRODUCTION OF ELECTRICITY

DR. G. STONEY, D.Sc., F.R.S.

This General Report covers the following papers :—

"Development of Fuelling Arrangements at the Vienna Municipal Electricity Works," by Ing. Fritz Siedle (J1).

The remodelling of the installation of the Municipal Electricity Works at Vienna for the utilisation of the poorer fuels available after the war by the installation of chain-grate stokers, improved combustion chambers and ashpits, as well as by the introduction of pulverised fuel.

"Researches with High Pressure Steam," by Dr. Jaroslav Havlíček (J2).

An extensive research into the properties of steam up to 253 atm. or about 3,600 lb. per sq. in. at temperatures up to 500°C.=932°F. A most complete apparatus has been fitted up to enable tests of the greatest accuracy to be made. Comparison is made with the figures given by Mollier.

"The Combustion of Tertiary Coal on Ships of the Royal Dutch Packet Navigation Company in the Indian Archipelago," by H. Th. Bakker (J4).

The Royal Dutch Packet Navigation Company has a fleet of 136 ships, of which 114 are coal fired, and are trading between the Dutch East Indian islands.

The coal available is Tertiary and has a large amount of volatile matter which at first caused considerable trouble in the firing to those accustomed to the harder European coals, and the best method of firing such coals is described.

In order to burn the cheaper slack, the application of mechanical stokers to water-tube boilers has been successfully tried and the Underfeed type of stoker has been found best.

On Scotch boilers mechanical stokers have been tried also, but the experiments, which are still being carried on, have not been successful up to the present. Full details of the method of working the stokers is given, and with superheaters steam temperatures of 300°C. have been easily maintained, the boiler efficiency having been raised to 80 per cent. with 12 per cent. CO_2 and funnel temperatures of 250—300°C.

It is only by the collaboration of the whole technical staff that such results have been obtained.

"Fuel Economy as practised by the German Federal Railway Company," by Ernst Harprecht (J5).

The State Railway is one of the largest consumers of fuel in Germany, using some 14.4 million tons of coal per annum.

The supervision and organisation as well as the testing and taking over of supplies is described and the requirements of various fuels, their testing both in the laboratory and on the road is discussed at length.

With regard to the utilisation of the fuels, the most appropriate selection and methods to ensure their most economic consumption are given.

"Economic Utilisation of Fuel in the Production of Electricity," by R. P. Sloan, C.B.E. (J6).

The total quantity of coal used for the generation of electricity in Great Britain is about 7.75 million tons per year or 4.3 per cent. of the total used in this country. This is not likely to increase much as although the use of current is rapidly going up, the economy of the power stations is increasing. Also supplies of waste heat are being further utilised. In one company, a reduction in the coal consumption of 21 per cent. is effected by the utilisation of such waste heat.

The cost of coal is relatively small in the case of small consumers such as small houses, and in typical figures given only amounts to 4.6 per cent. of the total cost in such a case. On the other hand for large consumers near the power station it may amount to 46 per cent.

To produce electricity at the lowest cost, the proportion between capital and other charges and the cost of fuel must be such as to result in a minimum.

Further economy must be sought by avoiding heat losses, pre-heating the air, bleeding or extracting steam from the turbine, re-heating and higher steam pressures and temperatures.

The subject of pulverised fuel versus automatic stokers is too big to be dealt with here.

In cases where process steam is required, large economies can be effected by the use of back pressure turbines, any excess or defect in the electricity required being made up by feeding into or taking current from the supply company.

Another direction is in the treatment of coal to obtain the by-products and use the resulting coke and gas under boilers, and a complete account of the by-product recovery plant at Dunston-on-the-Tyne is given.

The value of the derivatives from 1 ton coal is 10/6, and the value of the coke under the boilers 9/1, or a total of 19/7.

On the other hand the coal cost 12/- and the total cost of operation and maintenance 4/8, or a total of 16/8, giving a profit of 3/1, so that up to the present no important commercial economies have been obtained, but these costs could be considerably reduced by working on a larger scale.

"Utilisation of Liquid Fuels for the Generation of Steam," by Commander A. L. P. Mark-Wardlaw, R.N. (J7).

A résumé of the development of the use of oil fuel, especially in British warships, and deals with the various classes of oils and their properties. It also deals with the various methods of burning the oils under boilers and the precautions necessary to get good results.

"The Burning of Polish Coal on Locomotives," by Stanislaw Felsz (J8).

An account of an extensive series of experiments on firing locomotive boilers with Polish, English and Russian coals, and especially deals with the conditions necessary for the best combustion of Polish coals. It was found that non-caking or slightly caking coals with a non-fusible ash and porous clinker were more suitable than rich coal.

"Estimation of Heat Losses when employing Natural Gas as Boiler Fuel," by Wiktor Wisniowski (J9).

In using natural gas under boilers the heat losses are different from those with coal firing. In each case the losses due to gas which is not burnt and chimney losses have to be considered.

The combustion of natural gas, especially Polish, is considered, and formulae are given for estimating the various losses.

"Polish Coal as Fuel for Locomotives," by S. Kruszewski. (J10).

The qualities of Polish, Russian, and English coal were tested in locomotives and their relative advantages determined, both from a running and a cost point of view.

"Methods Employed by the Polish Railways in order to Promote Fuel Economy," by Stanislaw Felsz (J12).

A most full account of the methods adopted to reduce the coal consumption on the Polish railways by careful training of the personnel, premiums for coal economy and better working conditions for the engines. The conclusion is also come to, that, on account of the various qualities of coal, the calories used should be made a basis, not the weight burnt.

"Formulæ for the Economical Ratio of Blending Coals for Steam Raising," by T. Sase (J13).

On account of the inter-action between one another of different kinds of coal when they are mixed, in some cases a higher evaporation can be obtained than with either coal separately, so that thus important economies can be effected. The method of calculating from tests the best mixture is given.

"The Application of Air-cooled Condensers to Locomotives," by Alf Lysholm (J14).

It is generally supposed that direct air-cooled condensers cannot be used on locomotives, but from the researches given here it is quite possible to use them within the space available.

A number of experiments are described on cooling elements, and from the results of these a condenser has been designed now being used on turbine locomotives of the Ljungstrom type, a vacuum of from 78 to 62 per cent. being obtained.

An interesting point is that the relation between fuel per unit distance and car weight follows a straight line similar to the Willans line for steam engines and steam turbines.

"The Principles of Flame Radiation," by T. Lindmark (J16).

The transmission of heat is by convection, gas radiation and flame radiation, which latter is partly chemical radiation and partly radiation from minute particles of carbon.

In the case of pulverised coal, the flame is increased by the fact that the particles increase in volume in burning and that there remains a very porous and inflated core of coke. This increase in volume has been found to be as much as eight times in some cases.

Recently work on the radiation of pulverised coal flames has been taken up by the Stockholm Technical University, and it is probable that their researches may have considerable effect on the design of radiation boilers.

"The Duty of the Fuel Technologist and the Training of the Stoker," by F. Smal (J17).

Until recently the training of the stoker has been purely practical, but to get the best result scientific guidance is necessary. This can be supplied by the fuel technologist, who, by tests, can determine the best thicknesses of the fire and the best draught to give the maximum economy at various loads.

This guidance then enables the stoker to obtain the maximum efficiency.

Trend of Development

The extraction of by-products from the coal before burning is becoming of increasing importance on account of the extra use of tars, oils, and petrols which in the future is likely to be largely increased. Boilers are becoming larger and larger, and with the increase in the size of the grates, trouble is being met with.

At sea, mechanical stoking is making slow but sure progress.

It is remarkable how slow marine engineers have been to adopt mechanical stoking, and adhered so long to the old and obsolete system of hand firing. Of course, there are difficulties peculiar to marine work to be met with, but they surely could have been overcome before now.

Air heaters are being more and more used with considerable resulting economy, but this, again, causes trouble with the grates and also with the brickwork, due to the higher furnace temperatures.

At the same time, pressures are rising, necessitating improved methods of manufacture. Steam temperatures are also rising, and are at present limited by the material for superheaters. If higher temperatures are to be utilised, some better material than mild steel, probably one of the alloy steels, must be used, at all events for the tubes exposed to the highest temperature.

As an alternative to burning the coal on a grate, pulverised fuel is being largely used, and will become of increasing importance in the future. Much more remains here to be done. The best methods of pulverising and storing the coal have yet to be determined and also how to deal with the very high flame temperatures, especially with pre-heated air, unless an excess of air is allowed and consequent reduction in the CO_2 content of the flue gases. Pulverised coal may have a great future on board ship.

With the introduction of forced and induced draught and also air heaters and economisers, the temperature of the flue gases has been reduced to a point where there is little tendency of the gases to rise when they leave the stack. At the same time, with induced and forced draught high stacks are not necessary. Hence the pollution of the surrounding atmosphere is often serious.

Again, with modern arrangements, a considerable part of the ashes pass up the stack and are deposited on the surrounding country.

The development of methods to prevent such nuisance will be necessary in the near future, more especially as power stations are rapidly increasing in size.

Large economies can possibly be effected by the blending of coals, owing to what Mr. Sase calls the "digestive evaporation" of mixed coals, but this is a problem in which each case will have to be considered on its merits.

On railways, economies can be effected by the more careful training of the staff, premiums for economy of coal and better train loads and hauls.

It is probable that the properties of high-pressure and temperature steam will be more accurately determined in the near future.

Experiments by various methods are being carried out in several countries, and it is to be hoped that there will be full collaboration between various experimenters in each country to come to an agreement as to the most probable values of the properties of steam at high pressures and temperatures.

Examination and comparison of the results obtained by different methods is of the utmost importance, as each experimental method is liable to systematic errors peculiar to that method, and each experimenter is apt to consider his own method the most perfect.

At present, there is no agreement as to steam tables to be used, and in guaranteeing the efficiency of a machine the steam tables used have to be stated.

There is room here for an International Commission, possibly on the lines of the International Electrotechnical Commission, if one has not already been formed.

DISCUSSION

FRIDAY, SEPTEMBER 28 (MORNING)

Section J

UTILISATION OF FUELS FOR STEAM GENERATION AND THE PRODUCTION OF ELECTRICITY

Chairman: THE HON. SIR CHARLES PARSONS, O.M., K.C.B., F.R.S.

THE CHAIRMAN, in opening the meeting, commented upon the importance of the subject to be discussed, and said that the facts stated in Mr. Sloan's paper which demonstrated that the by-products of a carbonisation process could be successfully and economically utilised for the purpose of the generation of electricity were specially noteworthy in view of the fact that three-quarters of the electricity in the world was produced by steam, generated by the burning of fuels, and only one quarter by water power.

DR. G. STONEY then read his General Report.

MR. R. P. SLOAN (Vice-Chairman, Great Britain) opening the discussion, said the General Report which formed the basis for discussion under this Section covered a wide range of subjects, and the Agenda contained items of a varied nature, though all were more or less representative of problems to be solved in the economic utilisation of fuel. Some of the problems which had to be considered were still a long way from the solution, and the expenditure of much time and money on research would be required before the solutions were reached. How long this would take would depend largely upon the extent of financial support the various research organisations received from those who ultimately benefited by their investigations. There was, he thought, in this country at any rate, much which should and could be done to co-ordinate the research work which was at present being carried out by various associations and individuals, and further to link up our researches with those of other countries. It would be seen from the General Report of the Section that a suggestion was made in this direction, *i.e.*, that an International Commission might be set up to co-ordinate the results obtained from research on the subject of steam at high pressures and temperatures.

The first item appearing on the agenda was the "Prevention of Nuisance from Products of Combustion: Smoke, Dust and Ashes." This was one of the important problems yet to be solved by large consumers of solid fuel. The emission of smoke was a constant cause of complaint due to the consequent pollution of the atmosphere and to the deposition of the substance on the surrounding country.

The prevention or mitigation of these troubles was becoming a matter of first importance, more particularly owing to the greater concentration of fuel consuming plants. Many contrivances had been introduced on the market to prevent the emission of grit from chimneys, but in spite of this, their use had not become sufficiently general to have had any appreciable effect, although some extension of their utilisation might be brought about by the Public Health (Smoke Abatement) Act, which was passed in 1926. There was also the question of the avoidance of the nuisance caused by the consumption of fuel for domestic purposes in open grates. An early solution of this problem might be found by suitable legislation along the lines that no new residences erected should be equipped with open grates, and, further, that the open grates in residences already in existence should, over a period of years, be replaced by one or other of the several systems which were designed for the purpose of preventing nuisances from products of combustion. Much attention had recently been drawn to the benefits to be derived from direct sunlight, but, so long as this pollution of the atmosphere continued, these benefits would continue to be denied to those living in thickly populated areas.

With reference to the second item of the agenda, which was "The Advantages of Coal Distillation yielding By-products before using Coal for the Production of Steam," the electricity supply industry was sometimes accused of being extravagant owing to its use of raw coal; and he thought we must accept this accusation as being true, but much good had been done by the low-temperature carbonisation of coal for the purpose of improving the economies of modern steam raising. A paper (*J6*), which was before the Section, entitled "Economic Utilisation of Fuel in the Production of Electricity," described the progress that had been made at the Dunston Power Station of the Newcastle-upon-Tyne Electric Supply Company, where a plant of semi-commercial size was in operation. The developments which had led up to the measure of success which had been achieved at Dunston, were initiated by the Newcastle-upon-Tyne Electric Supply Company and its associates, and extended over a period of ten years or so. The problem which they primarily set out to investigate was the development of a low-temperature carbonisation process to operate in conjunction with an electric power-station. During recent years Messrs. Babcock & Wilcox—the firm of boilermakers—took an active interest in this development, and quite recently this interest had been increased. The papers referred to showed that if the cash value of raw coal was taken as 100, after its distillation, two products were obtained: (*a*) Derivatives with a cash value of 87 (*b*) semi-coke with a cash value (on a thermal basis) of 76, or taken together, a 63 per cent. increase in the cash value of the raw coal.

While he did not agree with many of the extravagant statements which had recently appeared in the press (some of which purported to have emanated from himself, or at all events appeared to have had his approval, but for which he was in no way responsible), he

was sufficiently optimistic to believe that we were well on the way towards making a commercial success of the low-temperature distillation problem. Plants in number had been designed with excellent technical results, some of which had proved that the cost of their operation was not outside the range of practical commerce. In a country like Great Britain, where no natural oil existed, the economic solution of low-temperature distillation of coal was a matter of first importance; as, besides providing the means of producing large quantities of oil within its own boundaries, the value of its coal deposits would, in consequence, be enhanced, which might have a marked effect on the prosperity of the coal-mining industry.

Then there was the subject of "The Proportion between Capital and other Charges and the Cost of Fuel so that the Cost of Electricity might be a Minimum." As a supplier of large quantities of electricity for all kinds of purposes, it was not only his desire to see economies effected on the operating side of his cost sheet, but to see that capital charges per unit of output were decreased at the same time. He was afraid that this was not happening to any great extent, and such economies as had been achieved were not due to any reduction in the cost of plant and apparatus, but were due to the improved load factor of the electricity supply undertakings. The question of the proportion of capital and other charges to the cost of fuel was illustrated in the paper he had just referred to, and this showed that not very much could be done to cheapen supply to the small class of consumer of electricity by merely effecting economies on the thermal side, important as these might be, but it was the capital side that required the greatest attention.

Attention was also called in the agenda to "The Use of Mechanical Stokers at Sea," and this was no doubt an advance, though a long delayed one, on the old methods of hand firing. It should add important economies in the operation of coal burning ships and might possibly check the development now taking place in the use of oil as a fuel for marine purposes. A further development was the use of powdered fuel on board ship. In both these cases it might be found possible to make use of inferior and cheaper grades of coal than were in general use at the present time. Both the use of mechanical stoking and powdered fuel plants appeared to be making fair progress now that the tradition attached to hand firing had been broken.

Finally, Mr. Sloan referred to the last item on the agenda, *viz.* "The Relation between the Property of Steam at High Temperatures and Pressures obtained by Experimenters in Various Countries." The relation between the properties of steam under such conditions was a subject of increasing modern interest. The steam turbine had approached so near its maximum efficiency under the usual operating conditions as to pressure, and so much had already been done in the direction of improved vacuum, that it was to higher pressures we must turn for the attainment of greater efficiency. The results of recent research on the properties of steel and alloys

suitable for withstanding the effects of high temperatures had now made possible the use of far higher temperatures than would have been practicable a few years ago, and already a considerable number of extra high-pressure plants had been constructed; some experimental, but others in regular commercial operation. In certain cases pressures from up to 1,300 lb. per sq. in. had been adopted.

DR. JAROSLAV HAVLÍČEK (Czechoslovakia), who spoke in French, made a few comments additional to his paper on high-pressure steam tests, and indicated some of the results obtained more recently. Pressures ranging from 52 to 150 atm., and temperatures up to 500°C. had been investigated. The method employed by him for measuring the heat content of steam was the continuous measuring of the Thomson-Joule effect, and he claimed that this method gave greater accuracy than methods based on continuous measuring of the heat contents in the condenser, as the specific heat of the water differed up to 1 per cent., according to the investigation results of Lüdin, Dieterici and Barnes He commented on the fact that parallel tests were being carried out in various countries, and expressed the view that, when the results were available in the course of the next few years, it would be possible to prepare steam tables which would be sufficiently accurate for the purpose of commercial guarantees. In the name of the Masarykova Akademie Práce he declared himself willing to collaborate with the scientific pioneers of other countries, who were working at the solution of this problem.

PROF. DOUGLAS HAY (Great Britain) spoke on the subject of one of the factors on which much of to-day's material was based, *i.e.*, the price of coal, because with the improvement in load factor which might reasonably be expected in the future, the price of coal would form a larger proportion of the total cost than in the past. As a result of international over-production arising from a reduced world demand for coal, prices had to-day been forced below the cost of production. It was generally supposed that by shutting out uneconomic units by combination, and by adopting modern methods of coal getting, that even further reductions would be possible in the near future, but this was doubtful. About 1,000 collieries, mostly small and uneconomic units, had disappeared out of a total of 3,000. The remainder had almost completed reconstruction on the latest lines, and were overhauling their production methods in an endeavour to catch up with falling selling prices. Nevertheless, not even the best and most efficient collieries could make a living, and prices were still steadily falling. As a matter of fact, modern developments in fuel technology and fuel economy had to some extent injured the mining industry by curtailing its market. This was no doubt inevitable, but none the less was unpleasant. Not only so; but the steady replacement of domestic coal by gas, electricity and coke had substituted for the sale of a fuel worth 25s. per ton the sale of one costing barely half as much: and much less of it was required. Again, electricity works now expected to buy small coal, and in some cases unwashed low-grade slacks at approximately half the cost of production, so that the weight of the market was shifting from

the large high-grade fuel to the small cheap fuel, with the result that the average selling price still depreciated. Moreover, seams were getting more difficult to mine, and of lower quality, requiring more preparation for the market. Then wages in mines could not remain at their present level and would tend to rise, while further curtailment of the hours of work would further increase the cost of production, in an industry where 70 per cent. of costs were wages. All these factors were at work in every European country, and he considered that world coal prices would tend to rise steadily in the future. He was certain that the Weir Committee's estimation of a cost of fuel at 16s. per ton in 1940 was fundamentally false. The colliery market must in the future be widened by the finding of new outlets for various grades of fuel. He could not at that moment discuss classification of coals and specifications; the possible effect of carbonisation processes from which relief might be expected, but he wished to refer to one point, namely, the use of surplus heat and low-grade fuels for electricity generation. Recently he had the honour of giving evidence on this subject before the National Fuel and Power Committee, when he pointed out that at least twenty million tons of low grade fuels were at present being mined, but not marketed by the collieries in this country, and abroad the same phenomenon was found. This figure excluded some sixteen millions already being used by the collieries for their own purposes. Few electrical engineers realised the extent of power generation at collieries. Approximately one million kW. of generating plant was installed at collieries, mostly in the form of small scattered units. In one district, for which figures had recently been established, colliery generators produced more units per annum than the district power supply company. It was perhaps difficult for electrical engineers to realise that power could be produced in this way for one farthing per unit at the point of use, no transmission charges being incurred. As against this, a power supply company supplying the same colliery, had to make a charge for transmission, and must charge anything from one halfpenny to 1½d. per unit. In the case of a group of collieries, the difference between generating their own current and buying it outside, might mean a cost difference of from £5,000 to £30,000 per annum, which explained why power companies did not make much headway in obtaining collieries as customers. There had been of late a tendency for large colliery groups to seek to supply outside customers. With the grouping of collieries and the centralisation of by-product oven plants, there was a tendency to install medium sized power stations in conjunction with the oven plants. It was soon found that the available supplies of surplus heat and low-grade fuels were sufficient to justify enlargement of the power station to supply an outside market, and that such supplies could be given at a competitive figure, thus bringing to the collieries valuable additional revenue.

MR. WILLIAM ERDÖS (Hungary) said that he desired to speak on the subject of the different forms of mechanical stokers for different kinds of coal in connection with the papers *J*1 and *J*4, entitled as

follows: *J*1 "Development of Fuelling Arrangements at the Vienna Municipal Electricity Works"; *J*4 "The Combustion of Tertiary Coal on ships of the Royal Dutch Packet Navigation Co. in the Indian Archipelago."

Mr. Erdös asked the Conference to excuse him for continuing his speech in the German language. He continued as follows:—

Die zwei Hauptforderungen an einen mechanisch bewegten Stoker sind gegeben:—

(1) durch die Anpassung an die Kohlensorte.

(2) durch die rasche Anpassung bezw. Regulierbarkeit der Luft- und Brennstoffzufuhr, entsprechend der Aenderung der Dampfbelastung.

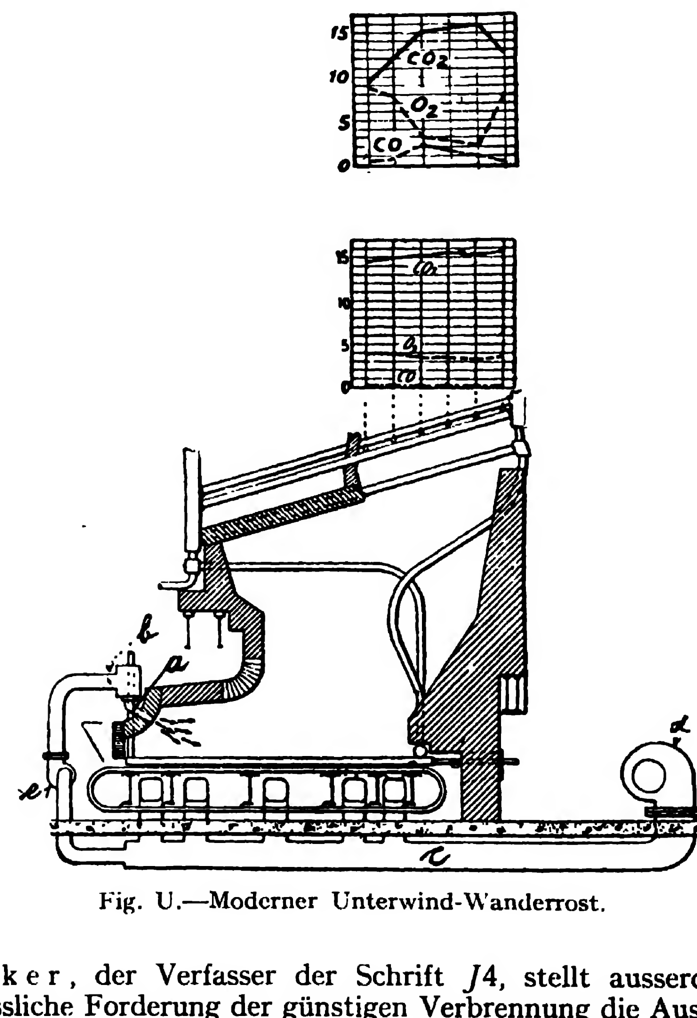

Fig. U.—Moderner Unterwind-Wanderrost.

Bakker, der Verfasser der Schrift *J*4, stellt ausserdem als unerlässliche Forderung der günstigen Verbrennung die Ausbildung eines genügend grossen Feuerraumes und einer richtigen Sekundärluft-Zuführung auf.

Bezüglich der Sekundärluft-Regulierung beziehe ich mich auf die

Versuche von E. Gunert auf modernen Unterwind-Wanderrosten der *Commonwealth Edison Co. in Chicago*, die mit Illinois-Kohlen ausgeführt wurden. Die Rauchgase wurden an mehreren Stellen entlang des Rostes geprüft, und das Resultat war, (s. Fig. U) dass die Kurven CO_2 und CO gegen Mitte des Rostes ihr Maximum erreichten und gegen Ende des Rostes stark abnahmen, hingegen hatte die O Kurve in der Mitte des Rostes, wo die Verbrennung am stärksten ist, ihr Minimum. Ein ähnlicher Charakter der Kurven ergab sich durch Messungen der Rauchgase bei den Wasserrohren (s. Fig. U oberes Diagramm).

Dem wurde abgeholfen durch eine Reihe von Sekundärluftöffnungen an der Frontseite der Gewölbe, durch welche Luft- oder Dampfstrahlen eingeblasen wurden. Die Wirkung war, dass die Kurven abflachten, der durchschnittliche CO_2-Gehalt um ca 2% stieg, und die Rauchplage stark vermindert wurde. *Das Wesentliche ist hier die intensive Durchmischung der Rauchgase und der Luft.*

Genau dieselben Resultate ergaben sich bei ähnlichen Versuchen in Ungarn, wo die Kesselbesitzer durch die neue Verordnung gegen die Rauchplage dazu verhalten werden, für womöglichst rauchlosen Betrieb zu sorgen.

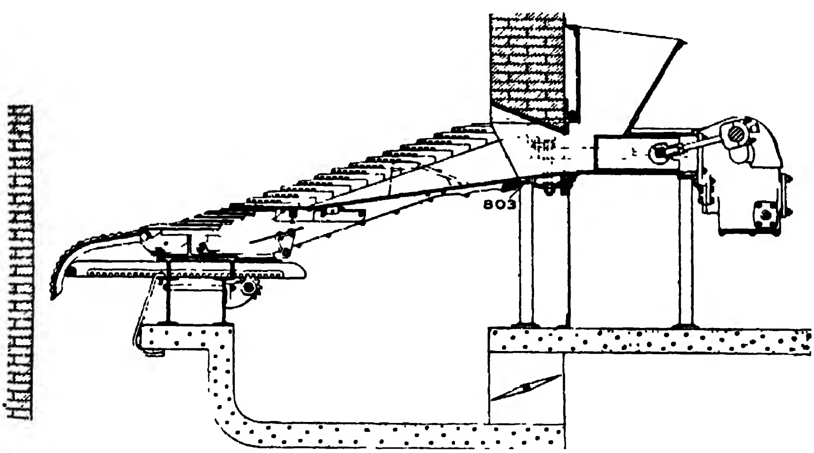

Fig. V.—Riley-Unterschubrost.

Als eine auf den Schiffen sich gut bewährende mechanische Feuerung wird von Bakker die Unterschubfeuerung angegeben. (Fig. V zeigt einen modernen Riley-Stoker). Die Primär-Luft kann in Abteilungen geregelt werden. Der Aschengehalt der durch Bakker angegebenen tertiären Kohlen beträgt 2·4%. Laut Mitteilungen im letzten Oktober-Heft 1927 der "Elektrizitätswirtschaft" (Berlin), soll bei Unterschubfeuerungen der maximale Aschengehalt nicht über 20%, der minimale Aschenschmelzpunkt nicht weniger als 1250°C. betragen. Für Kohlen mit niedrigerem Aschenschmelzpunkt, wie solche z.B. in Deutschland, in der Czechoslovakei, in Oesterreich und Ungarn häufig vorkommen, mussten die Vorschubroste entwickelt werden, welche die zusammenbackende Asche

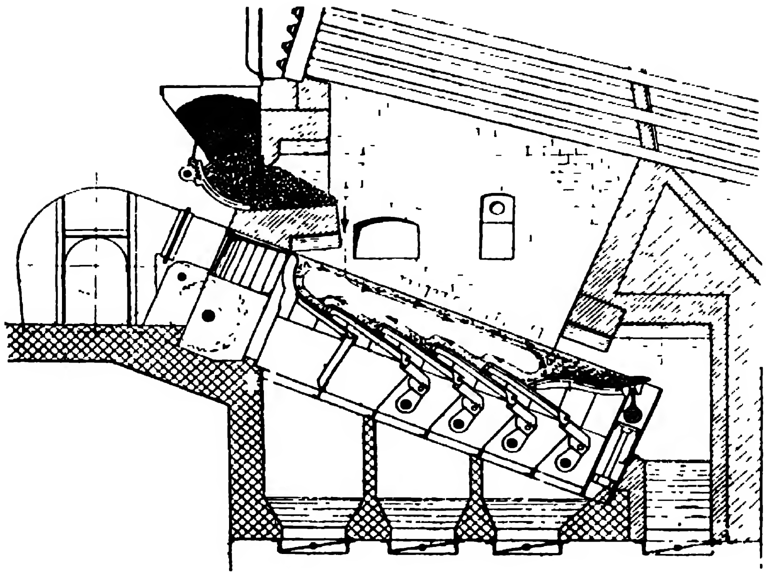

Fig. X.—Martin-Rückschubrost.

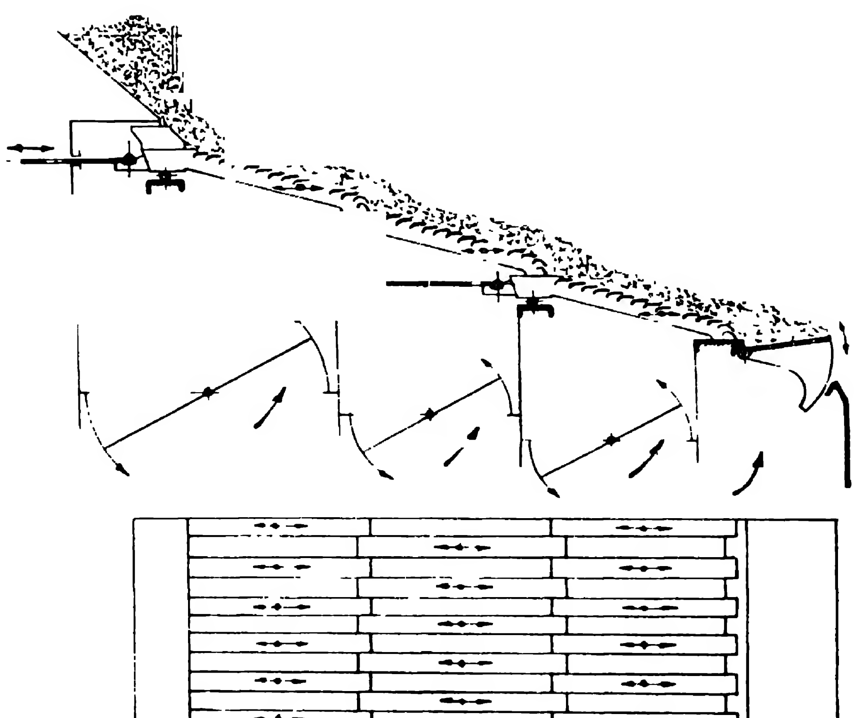

Fig. Y.—Record-Vorschubrost.

brechen und fördern. Als solche Roste haben sich u.a. bewährt: der Pluto-Stoker, welcher in der Schrift *J*1 beschrieben ist, dann der Lomschakoff-Rost, welcher in der Czechoslovakei ausgeführt ist. Der Lomschakoff-Rost ebenso wie der Martin-Rückschubrost (Fig. X), bestehen aus Roststufen, welche die ganze Rostbreite durchgehen und sich entgegengesetzt und alternativ bewegen.

Der *Record-Stoker* (s. Fig. Y), eine ungarische Konstruktion, weicht von obigen insofern ab, dass die beweglichen Rost-Stufen nicht die ganze Breite durchgehend, sondern in mehreren Gruppen schachbrettartig angeordnet sind und hierdurch sowohl in der Längs-, als auch in der Breite-Richtung ein Aufbrechen der zusammenbackenden Kohlen bezw. Aschenteile bewirken. Angaben über Versuche auf Record-Stokern und nähere Beschreibung sind in der Diskussion in Section *A* zu finden.

Einer der allerwichtigsten Gesichtspunkte ist die rasche Feuerungsregelung, welche am *Stettiner Kongress* 1927 der "*Vereinigung der Deutschen Elektrizitätswerke*" besprochen wurde. Um den durchschnittlichen Betriebswirkungsgrad der Kessel womöglich zu erhöhen, müssen die Kessel-Feuer der änderlichen Dampflast sehr rasch angepasst werden, was nur durch eine sehr rasche Luft- und Brennstoffregelung erreicht werden kann. Die modernen mechanischen Stoker müssen deshalb unbedingt eine gruppenweise unterteilte und regulierbare Luftzuführung haben, damit die aktive Rostfläche rasch verkleinert oder vergrössert werden kann.

Mr. I. V. Robinson (Great Britain) confined his remarks entirely to the paper by Dr. Havlíček on "Researches with High-Pressure Steam," and called attention to the suggestion at the end of the General Report as to the desirability of international action and agreement regarding the properties of high-pressure steam. Before the war Prof. Callendar, in London, investigated the properties of high-pressure steam, but there was then no outside incentive to urge him on, and progress was not very rapid. Naturally, there was a long break in the work, but in 1921 he noticed that the Americans under Mr. George Orrok were proposing to investigate the properties of steam up to and beyond the critical pressure. The work was divided up into a number of sections, and each section was allocated to a different investigator. One or two of the sections in the list that he had seen were not allocated, and he therefore suggested to the Electrical Research Association, which had a committee dealing with steam turbine matters, that this was a suitable opportunity for co-operation. As a result, we in this country offered and eventually agreed to take over certain sections of the work. As the result of the expansion of the work of each of the different investigators, it would be possible to draw up a complete table of the properties of steam based upon each investigator s work. It would be a most unfortunate thing if the Americans published one table, and we in this country published another, and someone on the Continent published a third, and so on. Therefore, he had suggested to Mr. Orrok that there should be a mutual agreement that no

country should publish any steam tables until there had been a comparison of the major facts and principles. That had been agreed between the Americans and ourselves.

Corresponding work was being carried out in Germany, and there also a similar agreement had been reached with them. Until the paper of Dr. Havlíček came under his notice, he was not aware that similar work was being done in Czechoslovakia, and his main object in speaking now was to extend a cordial invitation to Dr. Havlíček to co-operate with the British interests and to agree upon fundamental facts before any steam table was published in that country.

Thus, there were four countries working on this problem, and if there were others working on similar accurate method, their co-operation was cordially invited. There was room for international co-operation possibly on the lines of the International Electrotechnical Commission, if such a body had not already been formed. At the time of his initial discussion with Mr. Orrok, it had been a personal matter between them, and was not raised on behalf of any international body. The International Electrotechnical Commission had a committee, No. 5, dealing with prime movers, and that committee was busy at the present time drawing up an international specification for steam turbines. This committee met at Bellaggio twelve months ago, and when the question of steam tables came to be considered he had suggested, on behalf of the British delegation, that the matter should be left over for the time being, He outlined the reasons for making that request, as he had done that morning. There had been a further meeting at the Hague in May last, and again it was proposed to leave the matter over pending international action, and to leave a gap in the specification for the time being. That committee, he thought, was a suitable venue for dealing with such a matter. Where it was handled did not matter. The committee contained representatives of Great Britain, the United States, France, Germany, Canada, Italy, Czechoslovakia, Norway and Sweden, and whether the work was carried out by that committee or a committee in parallel with it, was of minor importance. The point was that he wished to take this opportunity to urge the necessity for international co-operation and agreement, and for that reason he was authorised to offer to Dr. Havlíček a cordial invitation to co-operate with the British and discuss matters with the other investigators, now that he was in this country.

M. Nils Forssblad (Sweden), referred to a new boiler in which the heat was transferred to the heating surface almost entirely by means of radiation. Two boilers of that kind were erected at the Vasteras Power Station, acting as a reserve steam plant on the system of the Royal Board of Waterfalls. The first boiler was oil-fired, and was started in March 1927. The second, which was arranged for pulverised fuel, was put into operation in April 1928. The boiler proper might be described as an internally fired, single-drum sectional unit. The combustion chamber was surrounded by six sections, each consisting of upper and lower headers, connected by 4-in. straight tubes. The upper headers were connected to a

horizontal cylindrical drum at the top of the boiler, whilst the lower headers were connected to a short vertical drum at the bottom. Between the upper and lower drums a 16-in. connector was arranged running through the centre of the furnace and protected by fire-brick. For high pressures this 16-in. connector could be replaced by a number of ordinary tubes. Burners were fixed at the six lower corners of the furnace and produced a flame around the connector in the centre, which acted as an ignition arch. The gases escaping at the upper ends of the sections, passed downward through two superheaters in parallel in the oil-fired unit or through a superheater at one side, and an economiser at the other side in the case of the second unit, and thence upward through an air heater to the fans and chimney. Thus the furnace was entirely surrounded by heating surface, and there was no additional heating surface outside the furnace. The unit, therefore, could be regarded as a recuperative steam furnace with superheaters arranged between the furnace and the recuperator. The air heater was recuperative, and consisted of a number of flat tubes of sheet metal through which the gas was led. The tubes were provided with filling members of corrugated sheet metal which divided them into a large number of straight, parallel channels. Filling members were also placed in between the tubes in order to form channels for the air which was forced through the heater, mainly in a direction opposite to that of the gas. The heater was compressed to a solid package whereby the corrugated sheets were brought into thermal contact with the partition sheets, and were stiffened by them. This rigid construction was specially advantageous at high temperatures, as in the Vasteras boilers the air was heated to about 1,100° F. As ordinary steel would not stand that temperature, the heater was partly built up from sheets of stainless steel.

The oil-fired boiler had been officially tested. The heating surface, calculated on the circumference of the tubes, was 2,350 sq. ft.; the maximum actual evaporation from cold water to steam of 280 lb. pressure and 800°F. temperature, was 88,000 lb. per hour, or 37·5 lb. per sq. ft. The efficiency was about 75 per cent. The boiler was started in eleven minutes from the cold state to full pressure.

The pulverised coal-fired unit has not yet been officially tested, but it seemed that the evaporation would be about 10 per cent. higher than that of the first unit. This boiler was fed with pulverised coal by two unit mills of the Babcock-Rema type. The boilers would serve as peak load and reserve units. The capital cost as well as the space occupied, was only about one-half that of the previous watertube boilers in the station, if evaporative capacity were taken as the basis. In cases where a high efficiency seemed essential, some additional heating surface should be arranged beyond the furnace.

MR. A. H. W. HELLEMANS (Holland), spoke of the possibility of the small generating stations of the large number of factories under certain circumstances supplying their surplus energy, not only at

a lower cost than large generating stations, but also with greater reliability. By accepting the use of high-pressure steam of about 30 atm. for industrial plants, the amount of surplus energy for backpressure installations would become far greater than it was now. Again, by comparison with large power stations, a factory owner would be able to supply a current for the public supply and to other works near by at a lower cost, because he already had his plant for his own purposes and, therefore, in calculating the cost at which he could sell his surplus current, it would not be necessary for him to take into account the capital cost of the installation.

The quantity of surplus energy available from industrial plants was not easy to calculate, but when it was seen from Mr. Sloan's paper that electricity works consumed only 7·6 per cent. of the fuel consumed by all the manufacturers of the country, this indicated that the large and small power consumers would easily be able to deliver in this country, as excess energy over that required for their own purposes, a larger quantity than that now produced by the power stations. At the same time, if this surplus energy would not suffice for the peak load, reliance would then have to be placed upon the power stations. Peak load power stations, however, need not be economical, and for this purpose there was no need to build great new super-stations, costing many millions sterling in capital expenditure. Old stations could be utilised for the purpose and the use of a number of such old stations, he contended, would also increase security in the case of industrial troubles. If such methods were adopted, some security would have to be given to the manufacturer offering surplus energy that his surplus would be made use of, and he suggested that the Government should take this in hand in order to be able to make use of such surplus energy. There were some examples of the adoption of the method which he had suggested, and one of them was that of the Gersweiler power station in Gienger, Bavaria. Since 1912, this station had worked in co-operation with two inter-locked power stations working at voltages of 15,000 and 5,000 respectively, the power stations of two towns, two wool factories, one factory for sanitary purposes, three grain mills and some small commercial enterprises; and this method had resulted in great security of supply. Mr. Hellemans concluded by reiterating the fact that in order to get electrical energy and at as low a price as possible, it was necessary to take into the general scheme, the surplus energy from the general manufacturing industries of the country, because, under the conditions he had outlined, they were able to supply more cheaply than power stations.

Mr. W. M. Selvey (Great Britain) said that the concentration of combustion in large centres, which was now the tendency, meant that larger quantities of used-up gases were discharged into the atmosphere at one point. If we looked at this matter from the point of view of consumption of oxygen rather than consumption of fuel, that would help us better to realise the new conditions to be dealt with in the future. The only suggestions that were before us at the

moment for dealing with smoke, dust and ashes; were the use of a number of stacks, and a return to the use of the very high stack. It was, however, one of the things which would have to be discussed in the future. Dealing with the distillation of coal, he said he was not quite sure that Mr. Sloan's paper was not in many respects the most important paper that had been before the whole conference. He wished to add his own appreciation of the process which Mr. Sloan had described in an extremely modest way, and he was also glad to hear his official disclaimer of the remarks that had been attributed to him in the daily press. He, personally, had been examining this matter for a great many years and had uniformly turned it down from serious consideration on various points. In Mr. Sloan's process, however, he thought he had found something which amounted to what he himself had laid down as the criterion; very much more than anything he had previously seen. This was seen from an examination of the balance sheet. First of all the ammonia had disappeared, and we were no longer dependent on the sulphate of ammonia for the balance sheet. Secondly, the low-temperature coke had disappeared, and we did not have to depend upon selling the coke at a very much higher price than was justified by its thermal value. Thirdly, the gas had disappeared and the electrical people would be profoundly thankful that they had not to tackle that problem One of the most striking things about the process, also, was that it used Northumberland coal which was a non-coking coal. It seemed to him that the system of drying coal could be extended to pre-heating to prevent balling up with bituminous coals, although perhaps it was not quite fair to ask Mr. Sloan to discuss this in an ordinary paper. Pre-heating, however, enabled the use of a producer type of structure with highly bitminous coals. Yet another thing arose out of this, which was that coking coals were comparatively small in amount, whereas the Northumberland coal was an ordinary good steam coal; so that the process would be capable of much more universal application than if it depended upon an extremely high volatile coal, which had been the basis of nearly all the fuel balance sheets he had seen so far. Yet another feature of the process was that it worked up its own by-products. For many years, the real profits of these processes had depended upon providing more or less end products, but the products in Mr. Sloan's balance sheet were not entirely end products. It seemed, however, that it would be possible to provide a motor car spirit. The products did spread themselves over a fairly wide market, because the derivatives were more than one in number, and they were the kind of thing from which other derivatives were in every day demand. Creosote was extremely valuable, for instance, and did not depend upon the oil industry, so that we were touching two or three markets. The only thing he was really bothered about,. and that came out in listening to the discussion, was that the balance sheet showed a profit of so much per lb. of coal, and was not worked out on the basis of so many tons of coal multiplied by certain prices, which meant a certain balance in the bank.

Large financial combinations could look after themselves, but he wanted to feel reasonably certain that that profit did go to the electrical end of the business. In conclusion, Mr. Selvey said that the businesses which had stood up best to the conditions which we had been passing through, both in this country and in America, were the public utility businesses, both company and municipal, and in making no distinction between the two he expressed the opinion that municipal public utility undertakings would tend to some form of company management. If the people concerned with coal mining desired to see their prosperity come back, they must begin to think of the idea that from the moment a shaft was sunk, until the ultimate product was delivered into the consumer's premises, that kind of constitution must be one, and more or less indivisible. He included in that other forms of public utility; gas, water, electricity and so on; there must be one organisation which dealt with a product, which should never be used in its raw state but should be so dealt with that it was developed into a large number of highly specialised products absolutely ready for use.

MR. GEORGE A. ORROK (U.S.A.), remarked that two-thirds of the power generated in the United States was from coal, and the amount generated from fuel oil was practically negligible except where the automotive vehicle came in where there was a very large amount of apparatus with a very low load factor. Progress towards the economic use of coal had gone so far in the United States, that the average fuel consumption for an output of 90,000 million kW. hours was 1·8 lb. per kW. hour, and that result was obtained with coal, with heating value varying from 8,000 B.Th.U. to 14,000 B.Th.U. per lb. The question of by-product plants in connection with central stations was solely a matter of economics. It was not possible to get more B.Th.U's out of a ton of coal when it was split up into thirty or forty different products than when a ton of coal was burned under a boiler in a power station. In the United States the prospects of selling by-products of coal at a reasonable figure were not good, and that fact would determine the advisability of the treatment of coal to that end.

The problem of getting rid of the smoke, dust and ashes after fuel combustion was a serious problem from the point of view of the nuisance caused, and a great deal of money was being spent in America to reduce that nuisance. At the present time, the larger power stations were given a clean bill of health by the Boards of Health; that is where stokers were employed, and some kind of washer or dust catcher, which caught 90 to 95 per cent. of the particles going into the stack, was installed. With powdered fuel another problem was encountered, and so far he had been unable to learn that anybody was doing, over a period, much better than catching 80 per cent. of the dust particles going into the stack. In certain circumstances it was possible to increase this to 95 per cent. if there was room to install the apparatus, but 80 per cent. was about the best that was being done on the average. At the same time, some plants claimed that they made no ash!

The subject which was closest to his heart, however, was the Properties of Steam. In talking this matter over with some of the British representatives on the previous day, it was suggested that he should say something at the Conference on the progress being made in America in this direction. This research work had been going on in the United States for eight or nine years. It was started by a little group of engineers who were contemplating the use of higher pressures and knew that the steam tables above 200 lb. and 400°F. were not backed up by actual tests, but were mainly extrapolated. Consequently, a series of researches was planned following three general lines, and arrangements were made to raise the necessary funds. That part fell into his own hands and he had been able to raise about $70,000, and the various institutions that had carried out the work had furnished a further $40,000 to $50,000, so that something like $120,000 had been provided in all for this research work. The first part was undertaken by Dr. Harvey N. Davis of Harvard University, who had in his laboratory the necessary apparatus for ascertaining the Joule-Thomson effect, and a little money spent on this apparatus put it into very much better shape. This part of the work occupied three and a half years under the direction of Dr. Kleinschmidt, and about 140 determinations were made, representing some 5,000 or 6,000 readings. The second part of the work was carried out in the Massachusetts Institute of Technology under the supervision of Dr. Keyes, Professor of physical chemistry, who worked with a pure nickel bomb of known contents in connection with the dead weight pressure gauge and a calorimeter, which was very sensitive and maintained nearly constant temperature at the point he wished. Dr. Keyes had produced the pressure-temperature-volume relation of water and steam through both the water and the vapour phase from 4,500 lb. per sq. in. down to 120 lb., and he ran from atmospheric temperature up to 800°. Higher temperatures had not yet been tackled but preparations were being made. The third set of researches was entrusted to the Bureau of Standards, under the direction of Dr. Osborne, who had made a special calorimeter and was working on the direct measurement of the specific heat of liquid water. This measurement had been carried up to about 450°F. and was rapidly being extended to the critical point. This calorimeter would also enable a figure to be obtained for the total heat of saturated steam from which the latent heat could be obtained. After these researches had been completed, Dr. Osborne expected to run into the superheat phase and to get a direct measurement of the specific heat of superheated steam. All these researches were coming to a conclusion, and it was hoped that the results would be available by December 1, 1930, apart from the question of the specific heat of superheated steam. Meanwhile, the General Electric Company had been so interested that they put some of their men to work on a calculation of a new total heat entropy chart which it was hoped to have published by December. Later a tentative table would be published, but the final results would be held up until entire international co-operation had been secured by the

experimenters in Great Britain, Germany, Czechoslovakia and the United States.

MR. F. D. NAPIER (Great Britain), expressed the hope that Mr. Sloan's paper would be studied not only by engineers, but by the politicians, so that we should get less of the unhelpful suggestions of the kind that had recently been appearing in the daily press. Mr. Sloan had come to the conclusion that pulverised firing of boilers could only be made a success under special conditions. To him, personally, it seemed that pulverised fuel firing of boilers was only justified when large quantities of fuel were available which could not otherwise be used, and it seemed to him that very shortly even the burning of crude coal dust would be looked upon as an economic crime, because this dust could be robbed of some of its oil before being burnt. The paper contained information which had been a closely guarded secret for many years, and the Conference was indebted to him and his company for having made it available to the world at large. The process of low-temperature carbonisation described, had been proved beyond question a commercial proposition, but the author and his company very wisely decided to say nothing until that state of affairs had been reached. It must be a source of great satisfaction to Britishers to find that this country was so far advanced, and was able to produce the first reliable method of distilling coal on a commercial basis for power station use. As one of the very few men personally associated with this work, although not directly associated with the Newcastle Co., he could say from his knowledge of the past twelve months that the plant had run during that time without a hitch. At first sight it might seem that the plant was complicated, but he assured the Conference that it was not more complicated to operate than an ordinary boiler. Indeed, he would say it was a little less so, because owing to the many ingenious automatic controls that had been devised by the engineers and designers, the plant was nearly fool-proof. In the paper it was stated that the Northumberland rough slack which was used, was screened, and that was really done to try and avoid the known difficulties which occurred when handling a large quantity of dust in a retort. As a matter of fact, recent trials had been carried out at Dunston for many days without any screening, and that was very important, because if the whole of the fuel was treated there was a very large saving as regards the percentage of oils recovered. It was admitted that some slight modification of the existing plant would be necessary to enable this to be done, but no radical alteration would be required. The paper gave some of the results obtained, but he wished to emphasise that they had been obtained over a long period and were not estimates in any way. The Newcastle Co. had explored all the markets and knew exactly where they were, and if he might dare to criticise Mr. Sloan's figures it would be to say that they were a little on the conservative side. In the figures, the price of the semi-coke was taken at the same value as the initial cost of the fuel, the only right thing to do in the circumstances; but he suggested that by a slight modification of the plant it would

be possible to obtain a fair proportion of sizeable coke suitable for domestic use, and then a still better return could be shown. When there was no market for it that coke could be broken up and burned in the plant. In the cycle of operations described, the amount of clean steam required was very small indeed. Owing to the ingenious arrangement by which the hot coke was quenched, full use was made of the resultant steam which was returned into the process, and consequently the amount of clean steam required was reduced to the absolute minimum, a matter of extreme importance to the boiler engineer. In conclusion, Mr. Napier said that this question of low-temperature distillation was of vital importance, not only to Great Britain, but to the British Empire; particularly to South Africa and Australia, because it would enable us to hold a great deal of the trade at present going to other countries.

Mr. A. Spyer (Great Britain), said that when his firm, Babcock and Wilcox, entered upon the Newcastle scheme, as described in the paper, they were asked if they would supply a plant on this large scale and involving a somewhat costly installation. Working in conjunction with the Newcastle Co., they found the subject of great interest, and after spending a very large amount of brain power, not to speak of large sums of money, in perfecting the process and rectifying such weak points as occurred, it became apparent after some three years' working that it was a practicable scheme. The installation was not a mere laboratory apparatus, but a plant dealing with 100 tons of coal per day. Therefore, it was not a toy. Finally, after these three years' experience, the conclusion was arrived at that the system was of sufficient importance for his company to take an active part in its development, and he must say that the leading consideration, and the most important from their point of view in coming to this decision, was the national importance of some such system, and not merely any question from a mere manufacturer's point of view of a possible and small profit. An important point indicated by Mr. Sloan was that, if they could persuade consulting engineers, users and their advisers to standardise on the pressures and temperatures they required for use in power stations, it would enormously cheapen the cost to them of the plant required for that purpose. Among the principal factors in the present-day high cost of plant from the actual expenditure point of view were the constant and continuous changes and the fact that nearly every installation to-day was absolutely special in its character, and there was no such thing for the moment as standardisation. Mr. Sloan's observations upon pulverised fuel were of great interest and importance. Personally, he rather feared that at the present moment pulverised fuel was suffering from the well-meant but exaggerated claims of its friends, and there was danger of a reaction which would not at all be justified. At Dunston his company had themselves installed a pulverised fuel boiler for several reasons. First of all, it was necessary to gain assurance that the duff which was resulting from the process could satisfactorily be burned under a boiler in a pulverised form when necessary;

secondly, that the coke produced could also be pulverised and satisfactorily burned; and, incidentally, it was desired to make an experiment as regards the evaporative duty of the tubes in the furnace of a pulverised fuel boiler and to measure what work these tubes were doing, the object being to throw some light on the various theories which had been put forward with regard to radiant heat effect. The observations in Mr. Sloan's paper with regard to the economies obtainable by the system were on the conservative side. The paper indicated that there was a direct gain, on the basis of a lb. of coal, of something like 25 per cent. Against this had to be set other considerations such as capital cost; nevertheless, it was fairly certain that the dollar efficiency, from the point of view of the producer of the current, would be increased. One speaker, representing the collieries, seemed to fear that the introduction of such a process would reduce the output of coal, but actually the contrary would be the result, because there was no claim for an increased thermal efficiency in steam production. Therefore, the same quantity of fuel would be required for producing steam as before, and there would be used an additional quantity of fuel from the collieries which would be converted into extremely valuable by-products.

MR. H. VAN HETTINGA TROMP (Dutch East Indies) drew attention to the paper of Mr. Coninck Westenberg, in Section *A*, dealing with methods of utilisation of Dutch East Indian coals, which gave a great deal of valuable information. Having had long experience of the Dutch East Indian coalfields, he knew the trouble there had been there to discover the most suitable methods for treating the coals, in order that the greatest possible economic use could be made of them. Not a great deal had been said concerning briquetting, but he saw a great future for the introduction of briquetted high-grade, non-cokable fines for marine purposes.

Instead of using oil, much greater use should be made of the high-grade slack or fines from semi-bituminous or anthracite coal, in the form of briquettes, for both the navy and the mercantile marine, and he suggested that the Conference should pay special attention to this aspect of the matter. In this connection, he said, it was interesting to notice that, although the Dutch East Indies were an oil-producing country, the Royal Dutch Packet Navigation Company, trading between the Dutch East Indian islands, had 114 coal-fired ships out of a fleet of 136 ships.

PROF. G. I. FINCH (Great Britain), spoke of the value of the centralisation of generating plants as a means for reducing the nuisance of atmospheric pollution. However, it was probable that this centralisation would take place in districts already densely populated, so that the problem of pollution of the atmosphere would become one of outstanding importance. When pulverised fuel was burned on a large scale, the problem would probably be a difficult one. It had been stated that in America probably 20 per cent. of the ash from pulverised fuel went out into the atmosphere and he saw some difficulty in reducing it much lower by ordinary means. In his

opinion, the only way of dealing effectively with this problem was to make energetic use of electrostatic means of dust deposition. In addition to the industrial user, there was another arch polluter of the atmosphere, and he was the householder who burned raw coal in an open grate domestically. He did not suggest that such people should be compelled by law to use central heating, or gas, or electricity exclusively, because the blood of our ancestors still ran strongly in our veins, and we were still fire worshippers at heart to-day. The domestic user demanded a cheerful open fire, smoke pollution or not, and the only way in which this demand could be satisfied, and at the same time atmospheric pollution at any rate reduced, was to provide a semi-coke or low-temperature coke instead of the coal he now so wastefully burned.

ING. DR. G. FORTE (Italy), said that some of the papers dealt with what was being done by the Belgian, German and Polish railways, in order to decrease the coal consumption of the locomotives. Similar work was being done in other countries, including Italy. As these methods had already been described, he would confine himself to saying that they had reduced the consumption of coal in Italy to three-quarters of what it was at the conclusion of the war. This had resulted in a saving of 1,200,000 lire per annum. In calculating the amount of coal necessary for locomotive work, it was necessary to take into consideration the gradients on the permanent way, because the consumption of coal could be double on a steep gradient what it was on a flat road. Therefore, on the Italian railways, they had introduced the conception of virtual length, *i.e.*, a length of straight and flat line running over which the locomotive did as much work as over actual gradients and curves. For gradients the virtual length was shorter than the real one, where the gradient was on the down slope, whilst in the case of an ascending line the virtual length was greater. When all the virtual lengths from station to station had been calculated according to a very simple formula, the work, the consumption, the premiums and so on, could be referred to these lengths without any need of calculating every time the resistance introduced by slopes and curves; thus simplifying the matter considerably. Another idea included in the premium for coal economy was to divide the premium between the organisation and the workers, and to reduce it according to one of the formulæ adopted. A further economy had been obtained by reducing the use of briquettes in the locomotive fire-boxes. The briquettes used on the Italian railways had not as high a calorific value as coal, whilst the price was 25 per cent. greater than that of coal. Before the war the use of briquettes had been reduced in Italy from 40 to 25 per cent., but as the result of experiments last year, and instructions to drivers, the consumption of briquettes had been still further reduced to 7 per cent., and he believed that it would be possible to work the Italian locomotives with only 5 per cent. of briquettes without increasing the total consumption of fuel.

MR. GEORGE HELPS (Great Britain) said he took it that the object of the World Power Conference was to endeavour to find out which

was the best power to use, and that must include fuel, because without fuel we could not get power. Having attended various meetings of the Sections, he was beginning to wonder whether that was really understood, because so far he had not heard it definitely stated what they were really chasing. He had already spoken at the meeting on Wednesday of Section G, and he had submitted with great respect that the only fuel to-day was gaseous fuel, but he had heard very little about that. He imagined it was because so few people realised first of all how cheap gas was, and secondly, because there were very few people indeed who knew anything about its use. He said that with profound respect to everybody who had worked at this subject. For his own part, he claimed to have done something in his own poor way, and at the moment he was applying gas to a Lancashire boiler and was expecting a wire at any moment to tell him the result; and the gas was being applied at a lower price than coal. He first made experiments in that direction ten years ago, but he went wrong, and it was only within the past few weeks that he thought he had seen where he went wrong. He believed that the result would be that the Lancashire boiler with gas fuel properly applied would give a higher efficiency than gas applied to the tubular boiler. He wished to ask one or two questions. Was it true that the heat obtained from coal depended upon the heat in it or its calorific value? Was it true, also, that the more divided the coal was, the more readily could it be expected to give up its heat? If the first was right, why was it that small coal was sold at half the price of large coal? If the second was right, gas was obviously the most finely divided state in which coal could exist. He understood that coke was used at Dunston, hot as it came from the retorts, to raise steam. As he understood it, the whole scheme at Dunston was a wonderfully sound one, but what he did not fully agree with was that the coke should be put to that use. Whilst it was true that very nearly the best duty was being obtained from the whole scheme by doing that, he did not think they were getting absolutely the best, because if the coke were converted into gas and applied to the boilers, labour would be cut out; and the atmosphere would inevitably be more clear.

Dr. G. Egloff (U.S.A.), referring to what Mr. Hood had said of oil-burning for heating purposes in the United States, said that a great deal of the trouble had been with the burners, but the Institute to which he had referred had taken care of this matter and had standardised the burners to such an extent that the mechanical troubles of three to five years ago had disappeared.

The improvement in the position as regards heating by oil was shown in the fact that whereas three years ago it cost from $800 to $1,000 to equip an eight or ten roomed house, better equipment to-day could be obtained for from $500 to $600. The result had been that to-day, 4 per cent. of the dwellings in the United States used oil heating.

Mr. Cz Mikulski (Poland) said that on behalf of authors of papers dealing with the methods of burning economically coal on

locomotives, he would point out that it would be very useful to get international agreement as to the following points. (1) To give always in the statistics the average calorific value of coal used, in calories or in the relative figures to the proposed standard coal. (2) To indicate the consumption of coal in relation to ton-kilometres and not to engine-kilometres, or at least in relation to the weight of train pulled. These propositions were of great importance with regard to the comparison of coal consumption on the railways in various countries. Therefore, it would be useful to obtain international agreement as to these propositions, and the Fuel Conference could facilitate the realisation of such an agreement.

The proceedings then terminated.

The following written contributions have been submitted:—

MR. W. BENTON JAMES (Great Britain). The two interesting papers on *Polish Coal for Locomotives,* numbered *J*8 and *J*10, fill me with admiration for the Polish Stokers. Men who carry out the "Method of Stoking" described in *J*8, page 701, by throwing into a 4·5 sq. m. grate some 180 Kg. (3½ cwt.) of coal every three minutes, and continue to spread it evenly over the firebed at the rate of 3½ tons per hour, must be men of exceptional physique.

It is a relief to find that the author of *J*10 confines himself to a maximum of only 700 Kg. per sq. metre-hour; which in the same grate only entails shovelling at the rate of 3 tons instead of 3½ tons per hour. His graph, Fig. 3, page 721, shows, that with best selected Polish coal, this high rate of combustion was required to evaporate 45 Kg. per sq. metre-hour in one of their standard locomotives, with a ratio of grate area to heating surface of 1 : 75.

Naturally one is led to enquire why such abnormally heavy combustion of Polish coal should be required to achieve this relatively normal rate of evaporation? Probably an explanation will be found by comparing the heating values given in the analyses on page 723, where a maximum of 7,860 calories for Russian and 7,388 for English, compares with only 6,609 for Polish, in the case of the coals actually tested. It is stated elsewhere that 6,300 calories is regarded by the railway engineers as a working average for Polish coal. One speaker has already mentioned in an earlier discussion that in the Italian railways they use coal from 6,800 up to 8,000 calories; and generally, throughout Europe, much higher heat values are demanded for railway work than the very low figures of 6,258 and 6 609 calories given for the best selected Polish coals. This high rate of combustion cannot be due to the type of locomotive, because in English railway practice, in locomotives of similar type the same rate of evaporation can be achieved on a combustion of about 450 Kg. against 700 Kg. of Polish coal. It goes without saying that such a result as this cannot be obtained except by using really good Welsh or Yorkshire coal; but the qualities used for these tests fifteen years ago as being representative of British Yorkshire and Newcastle coal, "without discrimination of collieries"; must have been some kind of rubbish which to-day no self-respecting English

railway engineer would think of using in his modern locomotives. To-day, three out of the four important railway systems in this country prefer for both their fast express and heavy merchandise locomotives, above any other kind of coal either English or foreign, the famous Barnsley Hards, produced from large modern mines in South Yorkshire, and known as Best South Yorkshire Association Hards; and a similar preference becomes yearly more decisive amongst all the leading European railway officials. Their high calorific value (7,700-8,000 calories), their hardness, and their low ash content (3-4 per cent. infusible below 1,300°C.), provide all the advantages and none of the drawbacks ascribed to the so-called Yorkshire Coal on page 722 of this paper.

If the following two points are marked off upon the graph (Fig. 3, paper *J*10), *viz.*:—

(1) $\frac{\text{Kg.}}{\text{m}^2\text{h.}}$ Evaporation 45, $\frac{\text{Kg.}}{\text{m}^2\text{h.}}$ Firing rate 450 as mentioned above.

(2) ,, ,, 37, ,, ,, ,, 335, which is about English standard practice; then the resultant curve for these Best South Yorkshire Association Hards will show a higher evaporation for any weight of coal burnt, and a lower consumption for any quantity of steam generated than that of any of the coals already appearing therein. I take it that the object of this Conference is not so much to find out the maximum quantity of fuel which can be burnt upon a given grate area in a given time, as to find out which kind of fuel will generate the greatest quantity of steam upon the lowest possible consumption.

Finally, in thanking the authors for these two interesting and informative papers, I would suggest that by laying down in their seaports a stock of really good English coal, such as the Best South Yorkshire Association Hards I have referred to, they would achieve the three-fold benefit of:—

(1) materially lightening the exceptionally heavy burden which appears to rest upon the shoulders of their locomotive crews; and

(2) they would raise steam for the long journeys between their mines and their ports, upon a much lower consumption and probably at a reduced cost.

(3) they would avoid the expense of equipping their locomotives either with any kind of forced draught appliances, or with spark-arresting nets. These latter appliances are practically unknown in English railway practice.

MR. CHARLES P. S. SPARKS (Great Britain), in reference to the paper presented by Mr. R. P. Sloan "The Economic Utilisation of Fuel in the Production of Electricity" (*J*6).

(1) The paper deals with a field in which there are many workers, and it is one of the first instances recording a real step forward. The development is of importance to three main industries, Coal, Chemical and Electric supply. In addition, it is of economic importance to the country in providing a potential source of liquid fuel suitable for transport and other purposes.

(2) From details of the process, the main features are:—

(i) Compact retort which enables it to be combined with the steam plant in a normal boiler house.

(ii) Delivery of hot coke fuel direct to the furnace.

(iii) Use of waste furnace gases for preheating the fuel.

(iv) Short period for distillation and coking.

(v) The high value of the bye-products (88 per cent. of the first cost of the fuel).

(3) The commercial value of the process mainly depends on the factors of capital cost and working charges as compared with the value of the bye-products.

Mr. Sloan, on page 655 of the proof of his paper states, "Under present conditions and at present prices, no important commercial economies have so far been obtained."

From examination of the paper, no indication is given as to the capital costs

From the General Report issued the morning of the reading, a profit of 3s. 1d. is deduced (19s. 7d.—16s. 8d.=2s. 11d.?) and it would be interesting to have Mr. Sloan's confirmation of this figure.

It is not possible to equate the commercial value of the process until the market has been tested on a larger scale to prove:—

(i) The average output of by-products from slack purchased at low values.

(ii) The average value of the volatiles (by-products), from such slack.

Mr. Sloan has rightly pointed out (page 654), the effect of a free market on cheap fuels—the same factor will also affect the value of by-products given (page 657), as 10s. 6d. for this plant. This would appear to be an abnormally high value, being 88 per cent. of the assumed value of fuel.

(4) In view of the difficult position of the coal industry, which has already been influenced by the economies effected by general electrification, improved methods of combustion and use of liquid fuel, the trend of fuel cost must be in an upward direction.

The full development of the process described in Mr. Sloan's paper should be of value to the electric supply industry in maintaining rather than reducing the present low fuel cost of electricity supply undertakings.

(5) The development of the process should be of marked importance to the coal industry, as 33 per cent. more fuel would have to be mined to obtain the same thermal output from any steam-raising plant.

The importance of further home supplies for the chemical industry and the provision of liquid fuels at home are economical factors, the value of which do not require special reference.

(6) *Influence of Capital Costs.*—I am glad Mr. Sloan has emphasised the importance of this item and its relation to the cost of the various classes of supply—otherwise there is a tendency for the Press to

over-rate the influence of reduction in fuel cost in reducing the cost of supply to the general public.

The figures given in the opening paragraphs of Mr. Sloan's paper, emphasise the extreme importance of capital costs, and I would like to say a word as to the great influence which simplicity in design has on such costs.

The interesting figures given in *The Engineer* of July, illustrate that low capital costs are being secured in Great Britain without sacrificing low operating costs.

The results of twelve months' working of the Padiham Station of the Lancashire Power Co. are compared with the best thermal results obtained in Great Britain. The Padiham Station has comparatively small generators—low steam pressure and superheat, and with an output of 45 million units at 35 per cent. load factor, had a thermal efficiency (twelve months) of 20·6 per cent.—as compared with the best results in Great Britain of: annual output, 300 million units; load factor, 53 per cent.; thermal efficiency, 21·8 per cent.

The cost of Padiham Station per kilowatt installed, was £12 7s., which compares most favourably with the capital cost of more elaborate stations.

When these results are equated, the higher capital cost of the station equipped with steam plant of a higher pressure and more efficient operation, results in a high cost per unit delivered by the more economic station.

(7) *Research.*—In conclusion, I would thank Mr. Sloan for having given us so many interesting details of this new development, which again emphasise the importance of continuous research.

SECTION K

UTILISATION OF FUELS, INCLUDING ELECTRICITY, FOR INDUSTRIAL FURNACE WORK

THE NUMBERS ARE THOSE GIVEN TO EACH PAPER FOR USE AT THE FUEL CONFERENCE

**Not prepared in time for presentation at the Fuel Conference*

DIE VERWENDUNG DER ELEKTRIZITÄT FÜR WÄRMEERZEUGUNG IN INDUSTRIELLEN UND GEWERBLICHEN BETRIEBEN

(THE USE OF ELECTRICITY FOR THE PRODUCTION OF HEAT IN INDUSTRIAL AND MANUFACTURING INSTALLATIONS)

AUSTRIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

DR. A. VELISEK

*Paper No. K*1

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ALLGEMEINES.—Durch den Verlust der Kohlengebiete nach dem Weltkriege und die Erschliessung der Wasserkräfte wurde in Österreich weitgehendes Interesse an der Elektro-Wärmeverwertung bei Industrie und Gewerbe sowie auch bei den Elektrizitätswerken erweckt, welch letztere die dringende Notwendigkeit empfanden, ihren Stromabsatz tunlichst ohne Erweiterung ihrer Erzeugungs- und Verteilungsanlagen zu vergrössern und so die Rentabilität der Stromerzeugung möglichst zu erhöhen. War man früher der Auffassung, dass die hochwertige elektrische Energie für Wärmezwecke wegen zu hoher Betriebskosten unwirtschaftlich sei und daher nicht in Frage komme, so hat diese Anschauung seither eine gründliche Wandlung erfahren. Mit ungeahnter Schnelligkeit hat sich die Elektrotechnik auch dieses neuen Zweiges der Elektrizitätsverwertung bemächtigt und heute ist dieses Gebiet nicht nur auf unserem Kontinent sondern auch in England und Amerika weitgehendst ausgewertet und ausgebaut. Wenn die weitgehendste Verwendung der Elektrowärme trotz ihrer ungezählten Vorteile bei uns in Österreich noch nicht im gewünschten

Masse Platz gegriffen hat, so ist dies lediglich auf die allgemeinen ungünstigen wirtschaftlichen Verhältnisse in unserer Industrie zurückzuführen und es kann nicht gezweifelt werden, dass sich mit zunehmender Besserung unseres Wirtschaftslebens auch in Österreich der Elektrowärmeverwertung ein bisher ungeahntes Arbeitsfeld eröffnen wird.

Soweit die Verwendung der Elektrizität für Wärmeerzeugung in Wohnungen, Büros und Geschäften in Frage steht, schreitet, wie ja allgemein bekannt, ihre Einführung rüstig vorwärts und man kann heute wohl sagen, dass Elektro-Kochtöpfe, Kochplatten, Brat- und Backrohre, Elektro-Küchenherde, Kochautomaten, Speicherherde, Heisswasserspeicher, Bügeleisen, Heizkissen, Brennscheren, Elektro-Öfen etc. wohl allgemein bekannt sind und auch zweckmässig verwendet werden. Eine zumindest ebenso grosse Bedeutung kommt nun auch der Elektro-Wärmeverwertung in rein industriellen und gewerblichen Betrieben zu, da es sich ja hier um weit gewaltigere Energiemengen handelt. Nach dem Gesagten ist es daher sicherlich nicht ohne Interesse, auf dieses neu erschlossene, weitverzweigte Arbeitsgebiet etwas näher einzugehen.

Elektro-Warmwasserbereitung.—Für die Elektro-Warmwasserbereitung kommen in erster Linie Elektro-Heisswasserspeicher mit Nachtstrombetrieb in Frage. Sie haben sich durch ihre weitgehenden Vorteile bestens bewährt und sind in Haushalt, Küche und Bad ebenso gerne gesehen wie in Hotels, Spitälern, bei Friseuren sowie in vielen industriellen und gewerblichen Betrieben. Kein Rauch und Russ, keine Feuersgefahr, kein lästiges Hantieren mit dem Feuerzeug, keine Vergiftung durch Abgase, keine Luftverschlechterung, weder Kohle, Staub noch Asche beeinträchtigen den Betrieb, er wird daher sauber, bequem und gefahrlos. Nicht zuletzt soll erwähnt sein, dass der Elektro-Heisswasserspeicher berufen ist, das Belastungsdiagramm und dadurch die Rentabilität der stromerzeugenden Unternehmungen zu verbessern, und dass ihm daher auch von dieser Seite das grösste Interesse entgegengebracht wird. Dies alles bewirkte, dass in Österreich Warmwasserkessel und Heisswasserspeicher mit ca 3 600 kW Anschlusswert angeschlossen werden konnten.

Elektro-Dampfkessel.—Für die Dampfgewinnung in Elektro-Dampfkesseln kommt derzeit nur die Widerstandsheizung in Betracht, bei welcher die Heizung nach verschiedenen Prinzipien durchgeführt werden kann, so dass sich bisher 3 verschiedene Systeme von Elektrokesseln ausgebildet haben, und zwar:

1. Elektrokessel mit indirekter Widerstandsheizung,
2. Elektrokessel mit direkter Widerstandsheizung,
3. Elektrokessel mit Elektrodenheizung.

Die indirekte Widerstandsheizung für Dampfkessel wurde vom Bau elektrischer Heizvorrichtungen übernommen und besteht im wesentlichen darin, dass die durch den Stromdurchgang sich erhitzenden Widerstände des Heizkörpers ihre Wärme durch Strahlung oder durch Leitung mittels gut wärmeübertragender Stoffe an das Wasser abgeben. Nach diesem Prinzipe wurden verschiedene Kesseltypen gebaut, welche aber alle an dem Übelstande leiden, dass die Stromkosten bedeutend höher als sonstige Brennstoffkosten sind, dass ferner die Dampferzeugung relativ langsam vor sich geht und die Anheizperiode unverhältnismässig lange dauert. Einen Vorteil bieten Kesselanlagen nach diesem System insoferne, als nur bei dieser Bauart sowohl Wechsel- oder Drehstrom als auch Gleichstrom verwendet werden kann, da die Stromleiter nicht in unmittelbare Berührung mit dem Wasser kommen und diese daher keiner elektrolytischen Zersetzung ausgesetzt sind. Für grössere Leistungen und höhere Spannungen ist dieses System aber ungeeignet, weil der Aufwand an Widerstandsmaterial zu gross und der Einbau einer zweckmässigen Isolation unmöglich ist.

Ein Mittel um grössere Leistungen bei Spannungen bis 1 000 Volt zu erreichen besteht darin, dass die stromdurchflossenen Heizdrähte direkt ins Wasser verlegt werden, womit sich dann das zweite System, das ist die elektrische Beheizung mit direkter Widerstandsheizung, ergibt. Da die Widerstände direkt ins Wasser verlegt sind, so kann dieses System ebenso wie das noch zu besprechende Elektrodensystem nur mehr mit Wechselstrom oder Drehstrom betrieben werden, da Gleichstrom bekanntlich eine Zersetzung des Wassers in seine Elemente Wasserstoff und Sauerstoff bewirkt, die zusammen das hochexplosible Knallgas bilden, das bei der Dampferzeugung wohl nicht besonders gefährlich erscheint, aber immerhin unerwünscht ist.

Das Anwendungsgebiet der beiden bisher beschriebenen Systeme findet darin seine Grenze, dass der spezifische Leitungswiderstand besonders bei Eisen mit zunehmender Temperatur wächst, wobei sich die Leistung im umgekehrten Verhältnisse verringert. Diese Tatsache führte schliesslich zur Konstruktion der dritten Art von Elektrokesseln, das sind die sogenannten Elektrodenkessel. Bei diesen Kesseln wird Hochspannungsstrom dadurch direkt für

die Dampferzeugung ausgenützt, dass das Wasser selbst als Stromweg benützt wird. Es ist also ersichtlich, dass bei derartigen Elektrodenkesseln das Wasser nicht nur die Rolle eines Betriebsstoffes sondern auch eines Konstruktionsmateriales spielt. Von derartigen Kesseln wurde eine ganze Reihe von Konstruktionen auf den Markt gebracht, welche sich mehr oder weniger voneinander unterscheiden. Kesselsysteme für Niederspannung sind anders gebaut als solche für Hochspannung, ferner trägt jedes Fabrikat seinen besonderen Stempel in der vorgesehenen Regelung der Dampferzeugung. Bei allen Kesseln aber kann gesagt werden, dass sie nur dort am Platze sind, wo es sich darum handelt, überschüssige Energiemengen, für die sonst keine Verwendungsmöglichkeit besteht, einer nutzbringenden Verwertung zuzuführen. Da dies in der Praxis fast ausschliesslich nur bei Wasserkraftanlagen zutrifft, erreichen Elektrokessel meist auch nur bei derartigen Anlagen die geforderte Wirtschaftlichkeit. Der Wirkungsgrad solcher Kessel ist allerdings sehr hoch und erreicht je nach der Leistung 95 bis 98%. Trotz dieser ausserordentlich günstigen Eigenschaft kann man jedoch nicht allgemein die Kohlenfeuerkessel durch Elektrodenkessel ersetzen. Wie gesagt, es bleibt das Anwendungsgebiet auch von grösseren Elektrodenkesselanlagen in der Hauptsache nur auf Wasserkraftwerke beschränkt, also auf wasserkraftreiche Länder. Unter dieser Voraussetzung bieten aber dann die Elektrodenkesselanlagen ganz ausserordentliche Vorteile. Es war in vielen Fällen durch sie möglich, den ganzen Betrieb eines Elektrizitätswerkes oder einer Fabrik wirtschaftlicher zu gestalten, wodurch riesige Werte an Volksvermögen gespart wurden. Da sich mit einer kWh unter Berücksichtigung des hohen Kesselwirkungsgrades etwa 1,3 kg Dampf gegenüber der 3 bis 4-fachen Dampfmenge bei Verwendung von 1 kg Kohle mittlerer Güte erzeugen lassen, kann behauptet werden, dass die Rentabilität von Elektrokesselanlagen im allgemeinen dann gegeben ist, wenn 1 kWh nicht mehr als $\frac{1}{3}$ bis $\frac{1}{4}$ kg Kohle kostet. Handelt es sich um die Verwertung reiner Überschussenergie, so wird mit je 3–4 kWh 1 kg Kohle gespart.

Ausser diesen Vorteilen, die der Betrieb eines Elektrokessels besonders bei überschüssiger Wasserkraft bietet, ergeben sich noch eine Reihe weiterer Vorzüge. Die Bedienung ist äusserst einfach, da sie bloss im Ein- und Ausschalten des elektrischen Stromes besteht. Der Fortfall jeglicher Kohlenzufuhr und Schlackenabfuhr sowie vollständiger Entfall der Rauch- und Russplage gestalten den Betrieb sauber. Elektrokessel sind sofort betriebsbereit und lassen

sich durch grosse Regulierfähigkeit allen Betriebsverhältnissen rasch anpassen. Der Raumbedarf ist ausserordentlich gering, die Dampferzeugung kann in unmittelbarster Nähe des Dampfverbrauches erfolgen. Alle diese Vorteile ermöglichen es, der Erstellung von Elektrokesselanlagen auch bei etwas ungünstigeren Stromtarifen näherzutreten.

Abb. 1.—Elektro-Dampfkessel 15 000 Volt Drehstrom, 2 250 kW. Der Kessel besitzt 3 Elektrodensysteme von je 600 und ein Elektrodensystem von 450 kW. Sämtliche Systeme sind einzeln regulierbar. Bei 8 at Überdruck können stündlich 2 800 kg Dampf erzeugt werden.

Im Rahmen dieser kurzen Besprechung ist es unmöglich, die einzelnen Kesselsysteme auch nur kurz zu beschreiben, doch soll wenigstens eine der gebräuchlichsten Ausführungen dem Wesen nach besprochen werden. Wie schon erwähnt, kommen für den unmittelbaren Anschluss an hochgespannten Wechsel- oder Drehstrom nur solche Bauarten in Betracht, bei denen das zu verdampfende Wasser selbst den Widerstand bildet. Die Überleitung des

elektrischen Stromes an das Wasser findet durch eiserne Elektroden statt, wobei Gleichstrom wegen seiner elektrolytischen Wirkung für den Betrieb von Elektrodenkessel ausscheidet. Bis zu 10 000 Volt Betriebsspannung werden derzeit alle 3 Elektroden vorteilhaft in einem Kessel untergebracht, bei Spannungen über 10 000 Volt erhält jedoch jede Phasenelektrode einen eigenen Kesselkörper. Die Verwendung des Wassers als Heizwiderstand bietet nicht unbeträchtliche konstruktive Schwierigkeiten, doch ist sie unbedingt notwendig, um vollständig symetrische Belastung der 3 Phasen zu erreichen. Das einstens gefürchtete Auftreten von Feuererscheinungen an den Elektroden ist vollständig vermieden und auch sonstige konstruktive Anordnungen, wie eine Reihe keramischer Einbauten im Kessel selbst, machen ihn betriebssicher Die Regulierung der Leistung geschieht ausschliesslich durch den

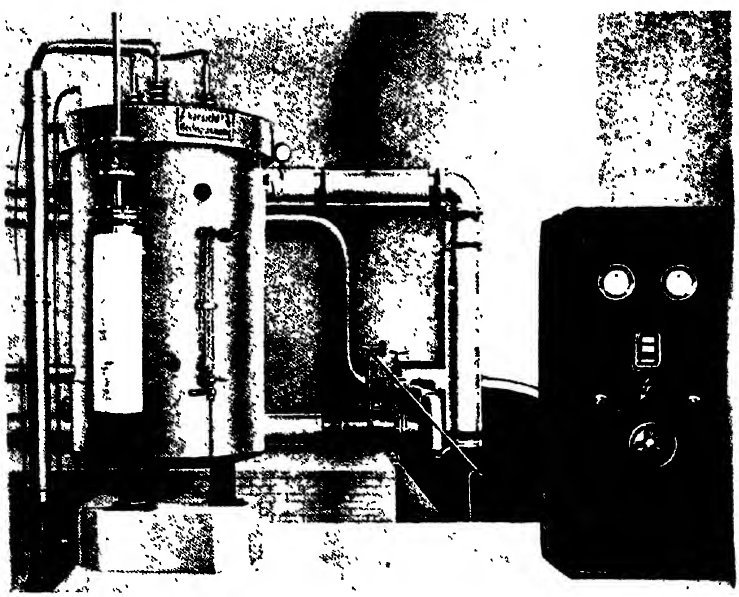

Abb 2.—Elektro-Dampfkessel 5 000 Volt Drehstrom, 1 500 kW, 10 at Überdruck, 1 875 kg stündliche Dampferzeugung.

Wasserstand ohne eingebaute mechanische Reguliergetriebe und zwar wird durch Hebung und Senkung des Wasserspiegels das aktive Wasservolumen vermehrt oder vermindert, ohne dass die Länge der radialen Stromwege irgend eine Veränderung erfährt. Mit Hilfe eines besonderen Wasserstandreglers, der zu seinem Betriebe nur ca 60 Watt erfordert, erreicht man eine Regelung auf konstanter. Wasserstand, man regelt somit auf konstante Leistung.

Zwei nach diesem System gebaute Elektro-Dampfkessel zeigen die Abbildungen 1 und 2.

Es soll noch kurz erwähnt sein, dass die Elektrizität auch zur Wärmespeicherung zum Zwecke späterer Dampfgewinnung nutzbringend herangezogen werden kann, indem sie in Form von Flüssigkeitswärme in einem Kessel von grossem Wasserraum gespeichert wird. Je nach der Konstruktion finden sich verschiedene Ausführungen. Man findet Speicherung mit natürlicher Zirkulation, es kann aber auch der in Elektrokessel erzeugte Dampf in dem Wasserraum eines Speicherkessels durch geeignete Düsen eingeblasen werden oder aber kann die Speicherung durch Umwälzungen mit Hilfe sogenannter Umwälzpumpen erfolgen. Mit Rücksicht auf die Anlagekosten sind im allgemeinen bei derartigen grösseren Speicherkesselanlagen Dampfdrücke von 6–8 at am wirtschaftlichsten, wobei dann der Speicherwirkungsgrad bei gut ausgeführten Kesselanlagen sehr hoch ist.

Das Anwendungsgebiet der Elektrokessel ist ein ausserordentlich grosses, sodass deren Anschlusswert in Österreich in verhältnismässig kurzer Zeit 17 000 kW erreichte. Alle Industrien, die Bedarf an Dampf zu den verschiedensten technischen Zwecken oder an Warmwasser haben, können mit Vorteil Elektrokessel verwenden. Insbesondere handelt es sich da um Zellulose- und Papierfabriken, Textilfabriken, Färbereien, Chemische Werke, Gummifabriken, Brauereien, Schlachthäuser, Badeanstalten usw. Auf Grund der ausserordentlich reichen Anwendungsmöglichkeiten ist dem Elektrokessel sicherlich noch ein weites Arbeitsfeld vorgezeichnet, das in um so höherem Masse beschritten werden wird, als der Ausbau der Wasserkräfte rüstig fortschreitet.

Formentrocknung in Giessereien.—Die Elektrizität wird gelegentlich auch in einzelnen Giessereien verwendet um Gussformen in Trockenkammern auf elektrischem Wege trocknen zu können. Die zu trocknenden Formen werden in die Trockenkammern gebracht, in denen unter Heranziehung der Nachtenergie die entsprechende Trockentemperatur herrscht. Die Wärme selbst wird beispielsweise dadurch erzeugt, dass ein durch ein Gebläse erzeugter Luftstrom entsprechend erwärmt und den Trockenkammern zugeführt wird. Die Temperatur der Räume selbst ist je nach Erfordernis verschieden und kann bis zu mehreren 100°C betragen. Anwendungen finden sich in Kerntrocknungsanlagen von Eisen- und Stahlgiessereien, in Bronzewarenfabriken und sonstigen Metallgiessereien. Diese Art der Trocknung ist sehr häufig rentabler

als die sonst übliche Trockenlegung mit Hilfe von Koks und erfolgt auf alle Fälle rascher, bequemer und einfacher.

Die elektrische Nieterhitzung.—Die elektrische Nietung ist in allen Zweigen des Brückenbaues sowie in den meisten Eisenkonstruktionswerkstätten in überaus grosser Zahl zu finden. Das Anwärmen der Nieten ist bei den in Betracht kommenden Mengen sicherlich ein Arbeitsprozess, bei dem grösste Wirtschaftlichkeit unbedingt am Platz erscheint. Bis in die jüngste Zeit erfolgte das Anwärmen der Nieten fast ausnahmslos im offenen Kohlenfeuer, gewöhnlich auf leicht transportablen Feldessen, die möglichst in der Nähe der Verwendungsstelle aufgestellt wurden. Man konnte dabei mit einem Verbrauch von durchschnittlich 150 kg Schmiedekohle für das Anwärmen von 100 kg Nieten rechnen, was sehr beträchtliche Betriebskosten verursachte.

Heute steht die Forderung nach äusserster Wirtschaftlichkeit an erster Stelle und es ist daher kein Wunder, dass sich in verhältnismässig kurzer Zeit das billigere und bessere elektrische Nieten weitgehendst eingeführt hat. Wo immer elektrische Energie in Form von Wechsel- oder Drehstrom zur Verfügung steht, ist die Überlegenheit des elektrischen Nieterhitzens allen anderen Erwärmungsmethoden gegenüber ausser Frage.

Der Nieterhitzer ist im Prinzipe ein Transformator, der Wechselstrom von einer beliebigen vorhandenen Spannung und Frequenz in Wechselstrom von ca 2 Volt Spannung, jedoch sehr grosser Stromstärke, umformt. Die Sekundärwicklung des Transformators besteht daher gewöhnlich nur aus einer Windung, welche durch das Arbeitsstück, den Niet, geschlossen wird und durch den durchfliessenden, oft mehrere 1 000 Ampere betragenden Strom in kürzester Zeit auf helle Weissglut gebracht wird. Da fast alle elektrischen Nieterhitzer regelbar sind, kann sich die Wahl der Hei stromstärke nach dem Verwendungszweck des Nietes richten und wird je nachdem, ob es sich um einen Tragkonstruktionsniet oder um einen Dichtigkeitsniet handelt, grösser oder geringer gewählt werden. Beim Eisenkonstruktionsniet soll das Schaftende, aus welchem der Schliesskopf gebildet wird, auf helle Rotglut erhitzt werden, während der Setzkopf dunkelrot bleiben kann. Dies wird durch rasche Erwärmung erreicht. Beim langsamen Erhitzen verteilt sich die Wärmemenge gleichmässig über den ganzen Niet, bis er schliesslich auf helle Weissglut kommt und als Dichtigkeitsniet, z.B. für Dampfkessel, verwendbar ist. Je nach Erfordernis werden die Nieterhitzer mit einer oder mehreren Einspannstellen versehen

um die notwendige Zahl von glühenden Nieten herstellen zu können. Für die Elektroden ist eine Wasserkühlung vorgesehen, die wenn möglich durch Frischwasser erfolgen soll.

Die Wirtschaftlichkeit der elektrischen Nieterwärmer ist hauptsächlich dadurch gegeben, dass diese Apparate eine präzise Überwachung der Erwärmung gestatten und jederzeit betriebsbereit sind. Unproduktives Warten für das Anblasen der Feuer fällt weg, Hitze, Rauch- und Russbelästigung in der Werkstätte sind verschwunden, der Transport und die Lagerung von Brennstoffen und Brennstoffabfällen vermieden. Die hohe Wirtschaftlichkeit der elektrischen Nietung äussert sich schliesslich noch darin, da jede Ausschussbildung vermieden wird, während diese bei der Feldesse mit 3-5% anzusetzen ist. Nicht zuletzt ist der geringe Verbrauch der elektrischen Energie zu erwähnen, der sich beim zweistelligen Nieterwärmer auf 28–38 kWh je 100 kg Nieten beläuft und bei dreistelligen bezw. einstelligen Nieterwärmern nicht mehr als 40, bezw. 45 kWh beträgt. Entsprechend der bequemen und wirtschaftlichen Arbeitsweise, die Nieterwärmer ermöglichen, konnte in Österreich ein Anschlusswert von über 800 kW erreicht werden.

Die elektrische Schweissung.—Mit Rücksicht auf den ungeahnten Siegeslauf der gesamten elektrischen Schweisstechnik und der damit verbundenen grundlegenden Umwälzungen in den einschlägigen Arbeitsgebieten sah sich der Fachausschuss für Schweisstechnik im VDE veranlasst, die Begriffsbezeichnungen und Begriffsbestimmungen einheitlich festzulegen. Demnach werden, soweit es das elektrische Schweissen betrifft, unterschieden:

(*A*) Widerstandsschweissung (Presschweissung)
- (*a*) Stumpf- und Abschmelzschweissung,
- (*b*) Punkt- und Nahtschweissung.

(*B*) Lichtbogenschweissung (Schmelzschweissung)
- (*a*) Flusseisenschweissung,
- (*b*) Gusseisenschweissung,
- (*c*) Kupfer-, Aluminium- und Rotgusschweissung,
- (*d*) elektrische Gasschweissung.

Zur sachgemässen Ausführung jeder Schweissarbeit ist gründliche Materialkenntnis unbedingte Vorausetzung und man kann ein gutes Ergebnis bei Ausführung irgend einer Schweissarbeit nur dann erzielen, wenn die notwendigen Kenntnisse der Metalleigenschaften vorhanden sind. Beispielsweise ist Roheisen nur nach dem Lichtbogenschweissverfahren schweissbar, während schmiedebares

Eisen auch noch nach dem Widerstandsverfahren geschweisst werden kann. Kupfer lässt sich mittels Presschweissung leicht verbinden, unter Zuhilfenahme passender Elektroden und eines entsprechenden Lichtbogens auch ohne weiteres mit der Lichtbogenschweissung, dagegen ist die punkt- und nahtweise Schmelzung nicht möglich. Messing lässt sich sowohl nach dem Press- als auch nach dem Schmelzschweissverfahren schweissen. Dasselbe gilt auch für Bronze, eine Legierung aus Kupfer und Zinn.

(*A*) *Widerstandsschweissung.*—Die elektrische Stumpfschweissmaschine besteht in der Hauptsache aus einem Schweisstransformator, den entsprechenden sekundären Verbindungskabeln zwischen Transformator und Schweissbacken, der Einspannvorrichtung, der Stauchvorrichtung und der elektrischen Schaltapparatur. Die Schweissbacken müssen mit Wasserkühlung versehen sein, um deren Abnützung in gewissen Grenzen zu halten und um zu vermeiden, dass sich die Wärme vom Schweisstück auf den Schweisstransformator überträgt. Die Wirkungsweise besteht kurz in folgendem. Die miteinander zu verbindenden Teile, das sind Drähte, Rundeisen, Flacheisen, Profileisen, Wellen, Rohre etc. werden in die stromführenden, schraubstockartigen Werkzeuge eingespannt, welche auf verschiebbaren Schlitten befestigt sind, so dass die eingespannten Teile zur Berührung gebracht werden können. Hierauf wird der Strom eingeschaltet, der die vorstehenden Enden in kürzester Zeit erhitzt. Nach erreichter Schweisshitze wird das weiche Material durch eine Stauchvorrichtung ineinandergedrückt; die entstandene Verdickung kann bei runden Querschnitten sofort nach erfolgter Schweissung durch ein passend geformtes Werkzeug, eine sogenannte Wulstpresse, welche von Hand, Fuss oder automatisch betätigt wird, entfernt werden. Bei grösseren Querschnitten wird die Wulst unter Ausnützung der Schweisshitze verschmiedet oder nach dem Erkalten weggearbeitet, wenn sie aus anderen Gründen nicht bestehen bleiben kann. Bei dünnwandigen Gegenständen, insbesondere bei Rohren, wird zur gleichmässigen Erhitzung des ganzen Querschnittes das sogenannte Abbrennverfahren angewendet, indem die Teile nach erfolgter Berührung so weit voneinander entfernt werden, dass sich ein Lichtbogen bildet, der eine gleichmässige Erwärmung auf Schweisshitze sichert. Zum Abbrennverfahren sind alle Stumpfschweissmaschinen über 10 kW ohne weiteres geeignet.

Mit dem gewöhnlichen Stumpfschweissverfahren, wie es zuvor geschildert wurde, können im allgemeinen alle normalen Eisen

geschweisst werden, jedoch nicht oder nur schwer hochwertiger Stahl, Kupfer, Messing und Aluminium. Um auch die letztgenannten Metalle mit Erfolg stumpf schweissen zu können, wurde in der letzten Zeit ein neues Verfahren, das sogenannte Abschmelzverfahren, entwickelt, das dem Wesen nach darin besteht, dass das sofortige Zusammenpressen der Schweisstösse zunächst unterbleibt, indem man im Schweissquerschnitt einen kleinen Luftspalt lässt. Erst nach dem Einschalten des Stromes nähert man die zu verbindenden Stücke ganz langsam bis der Strom in Form von Funken überspringt. Durch feinfühliges Gegeneinanderschieben der Schweissquerschnitte verursacht man so einen regen Stromausgleich durch Funkensprühen und schmilzt die Schweisstellen so lange gegeneinander, bis der ganze Schweissquerschnitt gleichmässig schweisswarm ist. Nun werden die Schweissquerschnitte schlagartig miteinander vereinigt. Dabei entsteht kein Wulst wie beim elektrischen Stumpfschweissverfahren, sondern ein perlartiger Stauchgrat. Dieses Verfahren hat für die Weiterentwicklung der grossen Stumpfschweissmaschinen ausschlaggebende Bedeutung gehabt. Es entstanden jetzt Maschinen zum Verschweissen von Eisenquerschnitten bis 20 000 mm² und mehr.

Nach diesem neuen Verfahren und mit den neuen Maschinen ist es nun möglich geworden, die elektrische Stumpfschweissung in der metallverarbeitenden Industrie umfassend zu verwenden. Es ist heute möglich, ausser der Verbindung von Eisen mit Eisen- und Stahlsorten aller Art auch Nickel mit Eisen, Nickel mit Kupfer, Nickel mit Nickel, Kupfer mit Chromnickelstahl, Kupfer mit Eisen, Kupfer mit Kupfer, Chromnickelstahl mit Schmiedeeisen und Chromnickelstahl mit Chromnickelstahl einwandfrei zu verbinden.

Zur Ausübung des elektrischen Abschmelzschweissverfahrens gelangen im Prinzipe dieselben Konstruktionen von Stumpfschweissmaschinen zur Anwendung, wie früher bei dem elektrischen Thomsonverfahren, jedoch musste die Sekundärspannung der modernen Abschmelzschweissmaschinen auf den 2- bis 3-fachen Wert der ursprünglichen Spannung gehoben werden, um das Aufrechterhalten des Abspritz-Lichtbogens möglichst leicht zu gestalten. Das Verfahren hat ausser dem früher geschilderten Anwendungsgebiete noch vielfach Verwendung bei der Herstellung von Schneidewerkzeugen aller Art; indem man beispielsweise bei Spezialbohrern, Aufreibern und Fräsern die eigentliche Schneidekante aus hochwertigem Schnellschnittstahl und die weniger beanspruchten Unterlagen und rückwärts liegenden Teile aus Siemens-Martin-

Stahl oder einfachem Eisen wählt. Hohe Bedeutung besitzt das Abschmelzverfahren bei der Verwendung von Rohrkonstruktionen aller Art. Mit den heute zur Verfügung stehenden Maschinen lassen sich Rohrverbindungen bis zu einem Aussendurchmesser von etwa 200 mm verschweissen, wobei die Schweissnähte derartige Festigkeit besitzen, dass man sich veranlasst sah, die elektrische Schweissung bedenkenlos in der Fabrikation von Hochdruckrohrleitungen, Stahlflaschen etc. einzuführen.

Das elektrische Abschmelzverfahren kommt aber nicht nur bei der Neuherstellung von Maschinenteilen in Frage, es gewinnt auch immer mehr an Bedeutung bei der Instandhaltung von Konstruktionsteilen aller Art. Auch in der Kabel- und Drahtindustrie hat dieses Verfahren Eingang gefunden und es werden daselbst Drähte bis herunter zu 1 mm stumpf geschweisst. Für besondere Zwecke sind auch besondere Maschinen ausgebildet, so z.B. Kettenschweissmaschinen zur Herstellung von Ketten aller Art und Grösse. Bezüglich der Wirtschaftlichkeit aller Stumpfschweissmaschinen muss gesagt werden, dass sie im allgemeinen nur dann rentabel sind, wenn es sich um Serienfabrikation handelt. Zum Schweissen kleiner, selten anfallender Mengen oder nur von einzelnen Konstruktionsteilen fallen die Verzinsungs- und Tilgungskosten der immerhin teuren Schweissmaschinen zu sehr ins Gewicht, wodurch die Ersparnisse beim Schweissvorgang selbst wieder aufgehoben werden. Die elektrische Widerstandsschweissung wird also vor allem in Betrieben mit grösseren Anfällen geeigneter Schweisstücke am Platze sein, aber auch in Ausbesserungsbetrieben, wie bei Bahnverwaltungen, Strassenbahnen, Eisenkonstruktionswerkstätten etc.

Eine zweite Verwendungsmöglichkeit des elektrischen Schweissens ergibt sich bei den Punktschweissmaschinen. Diese wurden aus der Stumpfschweissmaschine entwickelt und finden als Ersatz der früheren Nietung weitgehendste Verwendung. Die Maschinen selbst sind ganz ähnlich wie die früher besprochenen Stumpfschweissmaschinen gebaut und unterscheiden sich von diesen lediglich in der Ausführung der Elektroden.

Was die Ausführung der Punktschweissung anbelangt, besteht der Arbeitsvorgang darin, dass die zu verbindenden Bleche, Metallteile etc. zwischen die Schweisselektrodenspitzen gebracht und durch Druck auf den Fusshebel der Maschine zunächst zusammengepresst und unter Kontaktdruck gesetzt werden. Bei Weitertreten des Fusshebels wird der Strom eingeschaltet und die Schweissung vollzieht sich in wenigen Augenblicken. Auch bei der Durchbildung dieser Maschinen wurde auf solide Bauart Wert gelegt.

Die unangenehmen, induktiven Spannungsabfälle werden so klein als möglich gehalten und der Leistungsfaktor sowie der Wirkungsgrad auf ein möglichst hohes Mass gesteigert. Die meisten Punktschweissmaschinen lassen sich durch Auswechseln der Punktelektroden gegen Rollelektroden auch zur Nahtschweissung heranziehen. Sowohl Punkt- als auch Nahtschweissmaschinen erhalten ebenso wie die Stumpfschweissmaschinen Wasserkühlung der Elektroden. Um bloss an einem einzigen Beispiel den unglaublich geringen Stromverbrauch zu erkennen, soll erwähnt sein, dass beispielsweise zum Punktschweissen von 2 Stück 5 mm Blechen pro Punkt nur $\frac{1}{10}$ hWh verbraucht wird und dass bei diesen Blechen pro Stunde ca 700 Punkte mit einem Stromverbrauch von 70 hWh geschweisst werden können. Ähnliche Verhältnisse liegen bei der Nahtschweissung vor, wonach dieselben Maschinen nach Auswechslung der Elektroden zur Nahtschweissung von 2 Stück 1 mm -Blechen herangezogen werden können und sich pro Meter Schweissnaht ein Stromverbrauch von nur 1,7 hWh ergibt. Es sei noch bemerkt, dass es beispielsweise in der Blechwarenindustrie einem einzigen Arbeiter möglich ist, bis zu 15 000 Schweisspunkte bei 8-stündiger Arbeitszeit herzustellen.

Neben der Möglichkeit der Punktschweissverbindung von Eisenkonstruktionsteilen aller Art, von Eisenblechen und nicht zu hochwertigen Stahlblechen kann die elektrische Punktschweissung auch zum Verbinden von Messing und Zinkblechen Verwendung finden, soferne nur die Elektrodendicke etwas geringer gewählt wird. Es ist auch ohne weiteres möglich, Eisen mit Messing zu verschweissen.

Sowohl die Punkt- als auch die Nahtschweissung, insbesonders die letztere, verlangt metallisch reine Bleche gleichmässiger Stärke. Sind die Bleche auch nur unbedeutend verbogen, ungleichmässig oder verrostet, so findet bei der Schweissung keine gleichmässige Bindung statt, weshalb sich die Punkt- und Nahtschweissung im Ausbesserungswesen weniger als bei der Neufabrikation eignet. Ihr ausschliessliches Gebiet ist aber das Schweissen von neuen und dünnen Blechen, wo sie ausnahmslos die Nietung ersetzt. Die Festigkeit nahtgeschweisster Teile ist stets grösser als die des normalen Materials, da infolge der Verlappung an der Schweisstelle eine Verdichtung des Materials eintritt. Es ist ohne weiteres möglich, nahtgeschweisste Zylinder nachträglich zu börteln, zu drücken und zu ziehen.

(*B*) *Die Lichtbogenschweissung.*—Die Schweissung mit Hilfe des elektrischen Lichtbogens hat sich in den letzten Jahren überaus

erfolgreich durchgesetzt und hat die anderen Schweissverfahren in beträchtlichem Masse zurückgedrängt, umsomehr als die Lichtbogenschweissung eine ganze Reihe von neuen Schweissverfahren ermöglicht hat, die früher unausführbar waren. Es ist in den letzten Jahren gelungen, Schweissmaschinen mit zusammen ca 2 100 kW in Österreich anzuschliessen.

Das Prinzip der elektrischen Lichtbogenschweissung besteht darin, dass zwischen den zu verbindenden Metallstücken und einer in den meisten Fällen umhüllten Metallelektrode von geeignetem Durchmesser ein Lichtbogen gezogen wird, der die Metallstücke an eng begrenzter Stelle bis zum Schmelzpunkt erhitzt und das vom Elektrodenstab abtropfende Metall mit dem Schweisstück vereinigt. Die Umhüllung der Elektrode besteht aus einer, das Fliessen des Eisens begünstigenden Masse von ähnlicher Zusammensetzung wie die üblichen Schweisspulver. Sie bildet beim Abschmelzen eine Schlackenschichte auf dem flüssigen Metall, die es auf diese Weise vor chemischen Einflüssen der Atmosphäre schützt und zugleich entoxydiert. Die Länge des Lichtbogens soll ungefähr gleich dem Elektrodendurchmesser sein, der wieder mit der Dicke des Schweissgutes zunimmt.

Die Wahl der Schweisstromstärke richtet sich nach dem Arbeitsprozess; normale Werte sind 110 bis 185 Ampere bei Elektrodenstäben von 3–7 mm Durchmesser. Die Lichtbogenspannung beträgt während des Schweissens mit Eisenelektroden 20 bis 30 Volt, mit Kohlenelektroden bis 40 Volt und steigt vor dem Abreissen des Lichtbogens, soferne es sich um Gleichstromschweissmaschinen handelt, auf 60 bis 80 Volt, ist also so niedrig gehalten, dass auch bei direkter Berühung spannungsführender Teile keine Gefahr für den menschlichen Körper besteht. Die Durchführung der Schweissarbeit erfordert Schulung, ist jedoch leichter mit Gleichstrom als mit Wechselstrom durchzuführen.

Die Wechselstromlichtbogenschweissung verursacht zwar verhältnismässig geringere Anlagekosten, doch ist für Schweissungen, bei denen grössere Ansprüche an Festigkeit oder Dichtigkeit gestellt werden, unbedingt Gleichstromlichtbogenschweissung vorzuziehen.

Über die verschiedenen Vor- und Nachteile des elektrischen Schweissens mit Gleich- oder Wechselstrom wurden bisher eine Unzahl von Versuchen durchgeführt, um die Vor- und Nachteile dieser beiden Schweissmethoden möglichst klar zu legen, doch konnte bis heute eine vollständige Klarstellung nicht erreicht werden. Die bisherigen Proben ergaben, dass der Wechselstromschweissung der Vorzug der Billigkeit nachgerühmt werden muss,

während andererseits mit Wechselstrom nicht gleich günstige Festigkeitsergebnisse wie bei Gleichstrom erzielt werden konnten. Allen Proben mit Wechselstrom war gemeinsam, dass sie im polierten Schliff mehr Poren und Blasen zeigten als Gleichstromschweissungen, die von demselben Schweisser mit den gleichen Elektroden hergestellt worden waren. Der Wechselstromlichtbogen ist unruhiger, lässt sich nicht so genau führen wie der Gleichstromlichtbogen, worauf anscheinend die weniger guten Ergebnisse der Wechselstromschweissung zurückzuführen sind. Auch vom Standpunkt der stromliefernden Unternehmungen wird das Gleichstrom-Lichtbogenaggregat insoferne vorgezogen, als die Antriebsenergie dem Wechselstromnetz 3-phasig entnommen werden kann, wodurch sich im Gegensatz zur Wechselstromschweissung symetrische Netzbelastung mit weitaus günstigerem Leistungsfaktor ergibt.

Als Schweissgut kommt hauptsächlich Flusseisen, Stahlguss und Grauguss in Betracht, doch können mit besonderen Elektroden auch Bronze, Messing und Kupfer geschweisst werden. Die Dicke der zu verarbeitenden Bleche oder Metallstücke ist nach oben hin unbegrenzt, indem einfach mehrere Schichten Elektrodenmaterial bei Verwendung von dickeren Elektroden übereinandergelegt werden. Bleche mit einer Dicke von weniger als 2 mm können nur unter Aufwendung besonderer Sorgfalt, am besten bei maschineller Führung des Arbeitsstückes mit dem Lichtbogen geschweisst werden. Die durch die Schweissung erzeugte Festigkeit erreicht bei einer auf das Niveau der Nebenfläche abgearbeiteten Schweissnaht bis 95% des Nebenmaterials, kann aber durch Auftragen von Füllmaterial über das Niveau des Schweissgutes beliebig weit über 100% gesteigert werden.

Was die elektrische Schmelzschweissung von Nichteisenmetallen betrifft, muss betont werden, dass die einzelnen Schweissverfahren noch nicht endgültig durchgebildet sind. Praktisch kommen einstweilen nur die Metalle Kupfer nebst seinen Legierungen, Messing und Bronze, Aluminium und Blei in Frage. Da ihre Schmelzpunkte niedriger als beim Eisen liegen, so ist die Gefahr des Verbrennens durch die Lichtbogentemperatur mehr als beim Eisen gegeben. Am besten gelingt noch die Schweissung von Kupfer und seinen Legierungen mit Hilfe des Kohlenlichtbogens, wobei als Zusatzmaterial legiertes Kupfer benützt wird. Mit dem Wechselstrom-Lichtbogen misslingt aber die Kupferschweissung, da hiebei die Werkstückwärme nicht genügend ist und beim Durchgang des Stromes durch Null jedesmal soweit abkühlt, dass der Lichtbogen nicht aufrecht erhalten werden kann. Aluminiumschweissungen

werden bisher einwandfrei nur durch Gasschmelzschweissungen oder allenfalls unter Verwendung eines besonderen Schweisspulvers ausgeführt. Auch bei diesen Verfahren zeigt sich Aluminium der Schmelzschweissung sehr schwer zugänglich, da es in zu grosser Hitze sofort zu schlecht leitender Tonerde oxydiert. Rotguss-Schweissungen werden in ähnlicher Weise wie Gusseisenschweissungen durchgeführt, da in beiden Fällen wegen der sonst auftretenden gefährlichen Gusspannungen ein Vorwärmen notwendig ist, d.h. also, in diesem Falle muss das Kaltschweissverfahren dem Warmschweissverfahren weichen. Man schweisst mit Kohlenelektroden und bringt das Zusatzmaterial im Lichtbogen zum Schmelzen.

Es sollen noch 2 neue Schweissverfahren erwähnt werden, die beide darauf abzielen, gut bearbeitbare biegsame Schweisstellen zu erzielen. Die eine Methode besteht darin, dass ein Wasserstoffstrom zwischen den Elektroden hindurch geht. Dies hat eine ausserordentlich grosse Wärmeentwicklung im Lichtbogen zur Folge, sodass bei diesem Schweissverfahren weit höhere Temperaturen als bei allen übrigen erzielt werden können. Da der Wasserstoff ein sehr kräftiges Reduktionsmittel ist, werden alle Oxyde, die etwa noch auf der Metalloberfläche vorhanden sind, reduziert. Legierungen, die Chrom, Aluminium, Silizium oder Mangan enthalten, können auf diese Weise ohne Flussmittel unter Vermeidung aller Oxydation geschweisst werden.

Das zweite Verfahren beruht auf der Nutzbarmachung der chemischen und physikalischen Eigenschaften von Wasserstoff und anderen Gasen. Das Verfahren zielt vor allen Dingen darauf ab, die Bildung von Nitriden und Oxyden in dem durch den Lichtbogen abgetragenen Metall zu vermeiden und besteht dem Wesen nach darin, dass der Lichtbogen zwischen Metalldraht oder Kohle und dem Werkstück von einer besonderen Gasatmosphäre, wie reiner Wasserstoff, Wassergas, Wasserstoff-Stickstoffmischung, Amoniak-Alkoholdämpfe etc. umgeben wird. Niedrig gekohlter Stahl, Stahllegierungen und die meisten der Nichteisenmetalle samt ihren Legierungen können auf diese Weise in passenden Gasgemischen ohne weiteres geschweisst werden. Aus den Abbildungen 3 und 4 sind die Betriebskosten und Arbeitszeiten zweier moderner Lichtbogenschweissaggregate im Vergleich zum autogenen Schweissen zu ersehen.

Bezüglich der elektrischen Gasschweissung soll noch ein ganz neues Verfahren, das sogenannte Methanol-Lichtbogen-Schweissverfahren, Erwähnung finden. Man hat erkannt, dass man bei der elektrischen Lichtbogenschweissung bestrebt sein muss, der Eisenelektrode mit ihrer kleinen Masse möglichst wenig, dem massiven

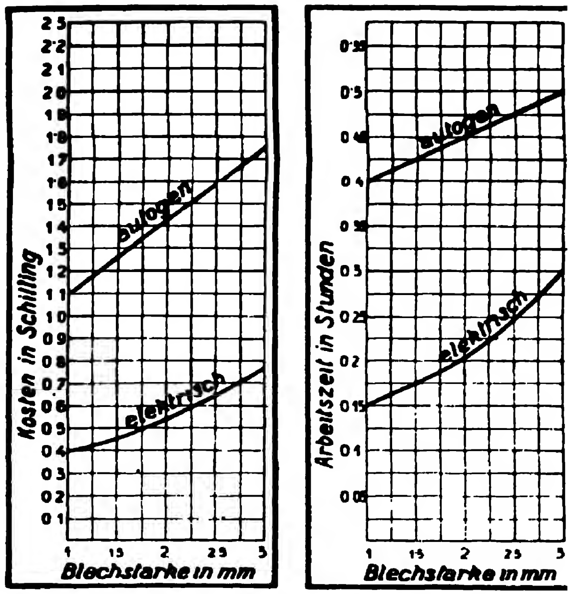

Abb. 3.—Betriebskosten und Arbeitszeit beim elektrischen und autogenen Schweissen.

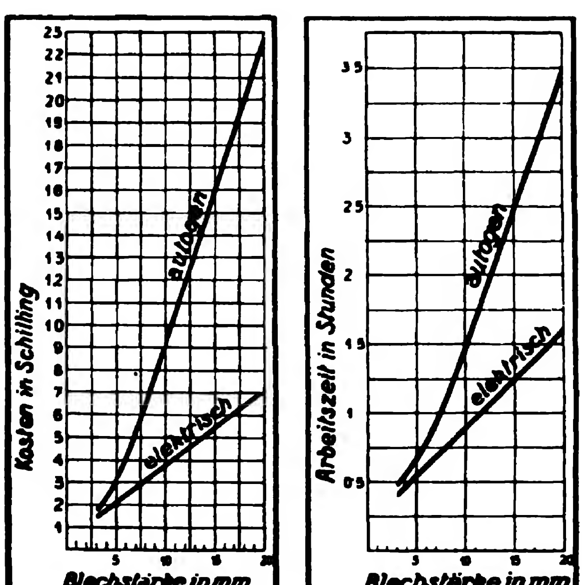

Abb. 4.—Betriebskosten und Arbeitszeit beim elektrischen und autogenen Schweissen.

Schweisstück aber möglichst viel Wärme zuzuführen. Dies geschieht bei der gewöhnlichen Gleichstromschweissung dadurch, dass man den positiven Pol mit seiner um rund 500°C höheren Temperatur an das Schweisstück, dem negativen Pol aber an die Elektrode legt. In allerletzter Zeit ist es nun gelungen, diese Temperaturdifferenz noch weiter zu erhöhen, indem man dem Lichtbogen Methanolgas zuführt, das bei etwa 700°C in Wasserstoffmoleküle und Kohlenoxyde zerfällt. Wasserstoff ist aber im Bereich der Lichtbogentemperatur nicht beständig, seine Moleküle spalten sich unter Aufnahme beträchtlicher Wärmemengen, die der Elektrode entzogen werden, in Atome. Beim Wiedervereinigen der Wasserstoffatome zu Molekülen und beim Auftreffen auf das kalte Schweisstück wird dann diese Wärme wieder frei, wodurch ein besonders gutes Durchschweissen der Schweissnähte erzielt wird. Bezüglich der Wirtschaftlichkeit dieses Verfahrens ist zu sagen, dass die stündlichen Schweissunkosten zwar fast doppelt so gross werden wie bei dem bisherigen Verfahren, dass dafür aber auch die Schweissgeschwindigkeit um das Doppelte steigt. Die Kosten für den laufenden Meter Schweissnaht werden daher, zumal das Zuschärfen bei Blechen bis zu 15 mm Stärke entfällt, trotz beträchtlicher Qualitätsverbesserung der Schweissverbindung nicht höher als bei der gewöhnlichen Lichtbogenschweissung. Es ist zu erwarten, dass dieses Verfahren nach entsprechendem Ausbau weitgehend Eingang in der modernen Schweisstechnik finden wird.

Elektro-Schmelz- und Hochöfen.—Man ist von anderen Gebieten der Elektro-Heizungstechnik her gewohnt, die Ausnützung der elektrischen Energie zu wärme-technischen Zwecken als im allgemeinen minderwertig anzusehen. Unwillkürlich bringt man dieses Gebiet in Zusammenhang mit den Begriffen Nachtenergie und Überschussenergie. Denkt man z.B. an die Erzeugung von Dampf im Elektrokessel, so zeigt eine einfache Überlegung, dass wirklich nur die billigste, selbstverständlich aus Wasserkräften gewonnene Energie hiezu Verwendung finden kann. Wirtschaftlich ein ganz anderes Bild erhält man aber dort, wo die spezifischen Eigenschaften der Umsetzung der elektrischen Energie in Wärme einen ausschlaggebenden Einfluss auf die Qualität des Produktes ausüben, was fast durchwegs bei metallurgischen Vorgängen der Fall ist. Zu diesen spezifischen Eigenschaften zählen in erster Linie die Neutralität der Atmosphäre im elektrisch beheizten Ofen, dann die erzielbare hohe Temperatur und auch die Gleichmässigkeit der Temperaturverteilung. Auf Grund dieser Eigenschaften kann daher z.B. im

elektrischen Stahlschmelzofen von den minderwertigsten Einsatzprodukten ausgegangen und dennoch ein hochwertiges Endprodukt erzielt werden. Über das, was der elektrische Glühofen in diese Hinsicht leistet, soll noch gesprochen werden. Die Rentabilität wird also hier in erster Linie von der Hochwertigkeit des Endproduktes beeinflusst. Daraus erklärt sich, dass nicht nur dort, wo Wasserkräfte zur Verfügung stehen, sondern auch in Gegenden, die in erster Linie auf kalorische Energiegewinnung angewiesen sind, das elektrische Schmelzen und Glühen immer mehr Verbreitung findet.

Was die Anwendung der Elektroöfen in der Nichteisenmetall verarbeitenden Industrie anbelangt, so kommen diese in erster Linie zum Schmelzen von Messing, in etwas geringerem Umfange zum Schmelzen von Nickellegierungen, Bronze, Neusilber und Aluminium in Betracht. Die wesentlichen Vorteile bei diesen Arbeitsprozessen bestehen. gegenüber dem rein thermischen Verfahren darin, dass grosse Wärmemengen auf einen verhältnismässig kleinen Raum vereinigt werden können, ferner in der hohen chemischen und mechanischen Reinheit der Wärmequelle, in der sicheren Einhaltung der gewünschten Temperatur und im Entfall von Feuergasen. Von den vielen durchgeführten Elektro-Ofen-Bauarten für das Schmelzen von Nichteisenmetallen haben sich bis heute nur der Induktionsofen, besonders für Kupfer-Zinklegierungen, dann der Lichtbogenstrahlungsofen, besonders für Kupfer-Zinnlegierungen und schliesslich noch der Hochfrequenzofen für besonders schwer schmelzbare Legierungen verwendbar gezeigt.

Dass die Elektro-Stahl- und Graugussöfen zufolge der eminenten Bedeutung des Eisens den ersten Platz auf diesen Gebieten einnehmen, ist begreiflich, wenn man bedenkt, welche hohe Bedeutung dem Eisen beim Aufbau unserer Kultur zufolge seines überaus häufigen Vorkommens in der Erdrinde zukommt. Das ganze Gebiet der früheren Österr. Ung. Monarchie, aber auch das jetzige Österreich, ist so reich an Eisenerzen, dass durch deren weitgehende Erschliessung über kurz oder lang die Handelsbilanz wesentlich gebessert werden wird. In dem gleichen Masse als der Ruf nach Ausbau der Wasserkräfte Gehör fand und Staat und Industrie ans Werk gingen, drängte sich auch der elektrische Hochofenbetrieb in den Vordergrund.

Der elektrische Hochofen bietet gegenüber dem gewöhnlichen Hochofen vor allem folgende Vorteile:

(1) Er erzielt eine Kohlenersparnis von etwa 60 bis 65%,

(2) Während ein gewöhnlicher Hochofen mindestens so gross gebaut werden muss, dass er 50 000 t Roheisen im Jahre liefert, ermöglicht der elektrische Ofen auch in viel kleineren Einheiten bis zu 8 000 t herunter noch anstandslose Betriebsmöglichkeit mit allen wirtschaftlichen Vorteilen.

(3) Der elektrische Hochofen ist wesentlich billiger als der gewöhnliche Hochofen gleicher Erzeugungsmengen und es stellt sich eine Anlage mit vielen kleinen elektrischen Hochöfen nicht teurer als eine solche mit gewöhnlichen grossen Hochöfen gleicher Summenleistung.

(4) Die Qualität des im elektrischen Hochofen erschmolzenen Roheisens ist besser. Es ist möglich, Roheisen mit überaus geringem Phosphorgehalt herzustellen, da der elektrische Ofen nur $\frac{1}{3}$ der ursprünglichen Menge an Reduktionsmitteln bedarf.

Um einen Vergleich zwischen der Wirtschaftlichkeit beider Ofensysteme zu erhalten, genügt es, die Preise für die folgenden Verbräuche einzusetzen. 1 000 kg Roheisen erfordern im gewöhnlichen Hochofen etwa 1 000 kg Koks, im elektrischen Hochofen etwa 350 kg. Dem gegenüber sind im elektrischen Hochofen 2 500 bis 2 700 kW und 6 kg Kohlenelektroden für je 1 000 kg Roheisen erforderlich. Da die übrigen Posten in der Rentabilitätsberechnung beider Hochofensysteme nahezu gleich sind, kennzeichnen die soeben angeführten Daten die möglichen wirtschaftlichen Unterschiede der beiden Verfahren vollständig. Für das Verarbeiten des Roheisens haben sich in wenigen Jahren eine Reihe von Elektro-Hochofen-Konstruktionen entwickelt, die im folgenden kurz gestreift werden sollen.

Bei den reinen Strahlungsöfen wird ein Lichtbogen zwischen Kohlen über dem Metallbade eingeleitet, welcher lediglich durch seine strahlende Wärme wirkt. Als Vorteil dieser Konstruktion ist zu erwähnen, dass keine Berührung zwischen Lichtbogen und Metallbad entsteht, womit sich ein sehr ruhiger Betrieb, leichte Anschlussmöglichkeit an öffentliche Zentralen und Entfall von automatischen Reguliervorrichtungen ergibt. Seine Nachteile sind die langen, schräg gestellten, leicht zerbrechlichen Kohlen, allzu konzentrierte Wärmemenge, daher ungleichmässige Erwärmung des Bades.

Der direkte Lichtbogenofen, bei welchem der Lichtbogen zwischen Elektrode und Bad spielt, vermeidet die zuvor genannten Nachteile.

Die Elektroden stehen senkrecht, können daher nicht leicht brechen, der Deckel des Ofens wird geschont, da die Wärmestrahlung nur nach unten direkt auf das Bad wirkt.

In weiterer Konstruktionsfolge entwickelten sich die reinen Widerstandsöfen, bei denen das flüssige Rohmaterial in einer Rinne zwischen Stahlelektroden durch direkten Stromübergang erhitzt wird.

Auf dem gleichen Prinzip basieren auch die Induktionsöfen, welche jedoch die Nachteile des vorhergehenden Systems vermeiden. Die Widerstandsheizung des Bades wird dadurch erreicht, dass dieses als Sekundärwicklung eines Transformators ausgebildet ist, dessen Primärwicklung hochgespannten Strom führt. Die Verbesserung liegt also darin, dass die Sekundärwicklung des Transformators, die Zuleitungen und die Elektroden entfallen. Als Nachteil ergibt sich nun der Umstand, dass für den Ofen nur warme Einsätze verwendet werden können und dass der Transformator konstruktiv mit dem Ofen vereinigt ist, daher unzulänglich gekühlt wird und schlechten Leistungsfaktor besitzt.

Als letzten Konstruktionstyp soll der Lichtbogen-Widerstandsofen erwähnt werden, bei welchem ausser den über dem Bade stehenden Hauptelektroden auch noch Bodenelektroden wirksam sind. Durch einen Zusatztransformator kann diesem je nach Bedarf eine regelbare Spannung zugeführt werden, sodass durch direkten Stromübergang im Bade auch eine Heizung von unten her stattfindet.

Es soll schliesslich noch erwähnt werden, dass sich die Arbeitsweise von Elektro-Hochöfen bei ganz bestimmten Schmelzstromstärken am günstigsten gestaltet und zwar müssen diese für die Einschmelzperiode, bezw. für die Raffinierperiode verschieden gewählt werden. Diese Stromstärken werden mit Rücksicht auf die Wirtschaftlichkeit des Betriebes bei grösseren Öfen meist durch selbsttätig regelnde Vorrichtungen konstant gehalten. Um den besonderen Verhältnissen in den einzelnen Fällen Rechnung zu tragen, sind automatische Reguliersysteme entwickelt, ein rein elektrisches und ein elektrohydraulisches System, welches jedes in seiner Art den Betriebserfordernissen vollauf entspricht. Die Abbildungen 5, 6, 7 und 8 zeigen moderne Elektro-Öfen, für deren Anschluss in Österreich bereits 27 300 kW erforderlich sind.

Der Vollständigkeit halber wäre nun noch die Verwendung des Elektro-Schmelzofens in anderen, nichteisenerzeugenden Industrien zu erwähnen. Es sind Arbeitsverfahren und entsprechende Ofentypen entwickelt, welche zur Erzeugung von Aluminium, Zink, Blei, Phosphor, Wolfram etc. verwendet werden, aber auch für

die Karbid-Industrie war die Entwicklung der Elektro-Heizung von hervorragender Bedeutung. Auch hier kam der elektrische Lichtbogenofen zur Anwendung, in welchem man versuchte, Oxyde der Erde und Alkalierdmetalle zu reduzieren, wobei sich aber als Endprodukt Karbide ergaben. Damit war der Anfang der Karbid-Industrie gegeben. Schliesslich kommt das elektrische Lichtbogenverfahren auch noch in der Graphitherstellung, ferner bei der Erzeugung von verschiedenen Ferrolegierungen zur Anwendung, denn es ist ja bekannt, dass die Elemente Mangan, Silizium, Titan,

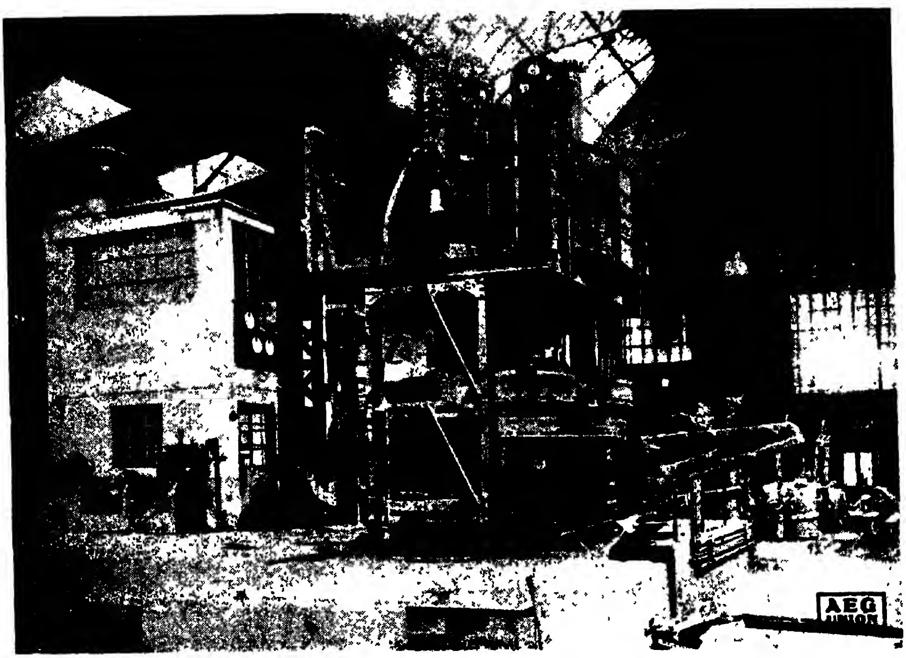

Abb. 5.—Elektro-Stahlofen, System "Fiat" nach dem Duplexverfahren arbeitend, 3 t Inhalt.

Chrom, Wolfram, Molybdän, Vanadium und Tantal ausschliesslich in der Form von Eisenlegierungen erzeugt werden. Schliesslich spielt der Lichtbogenprozess auch noch in der Stickstoffherstellung eine ausserordentliche Rolle, da er mit seinen überaus hohen Temperaturen die Möglichkeit der hiezu notwendigen chemischen Reaktionen gibt.

Elektro-Glüh- und Trockenöfen.—Die grosse Bedeutung, welche die warme Behandlung der Metalle und ganz besonders die der Konstruktions- und Werkzeugstähle auf deren physikalische Eigenschaften hat, macht es begreiflich, dass sowohl Grossindustrie

als auch Kleingewerbe eifrig an der Vervollkommung der hiezu dienlichen Apparate arbeiteten. Es waren insbesonders 3 Ziele, die man bei diesem Streben zu erreichen suchte und zwar: eine praktische, vollständige, gleiche Erwärmung des Arbeitsstückes, dann eine unbedingt sichere Einstellbarkeit der erforderlichen Temperatur und schliesslich eine Erwärmung des Glühgutes ohne Oxydation an seiner Oberfläche. Dass die Elektrizität als Wärmequelle zur Erfüllung obiger Bedingungen geeignet ist, liegt an der Hand. Es mangelte daher nicht an Versuchen, den Wünschen

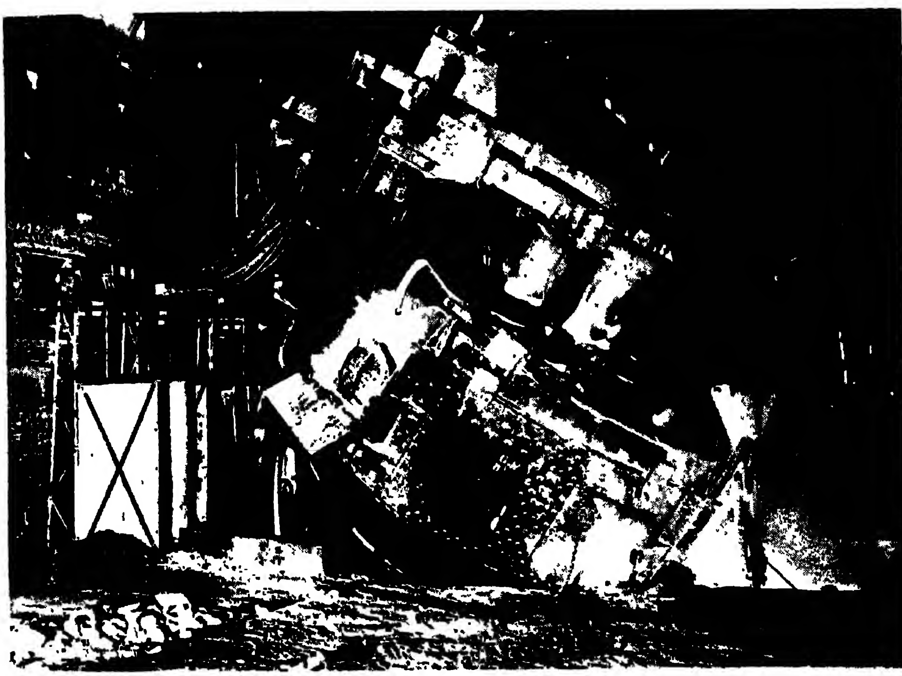

Abb. 6.—Elektro-Stahlschmelzofen, Fassungsraum 20 t, mit hydro-elektrischer Hand- und automatischer Elektrodenregulierung und hydraulischer Kippvorrichtung, Ofen in Kippstellung.

der verschiedenen Industrien gerecht zu werden, doch scheiterten zunächst alle vorgeschlagenen Lösungen am Fehlen eines geeigneten Materials für die Heizwiderstände. Weder Kohlenwiderstand, noch Widerstände aus gekörntem Graphit oder in Stäbe gepresstes Karborundum, noch Silitwiderstände konnten befriedigen, ebensowenig auch Platin, das wohl Temperaturen bis zu 1200° dauernd verträgt, jedoch wegen seines hohen Preises ausscheidet. Als aber die Stahlindustrie dank ihrer Fortschritte in der Herstellung rostfreier Stähle und hoch hitzebeständiger Chrom- und Nickellegierungen das zum Bau von Heizwiderständen notwendige Material

geschaffen hatte, eröffnete sich dem Glühofen sofort ein weites Arbeitsfeld.

Für die äusseren Formen eines solchen Glühofens sind die durch die Fabrikationsbedingungen gegebenen Dimensionen des Glühraumes massgebend. In den meisten Fällen findet man mit parallelepipedischen Formen das Auslangen, gelegentlich werden aber auch Rundöfen gebaut, wenn die zu glühenden Stücke in zylindrische Einsatzgefässe gelegt werden müssen. Die Öfen bestehen aus einem Metallgehäuse, die Vorderwand meist aus Gusseisen, Seitenwände und Rücken aus Stahlplatten, die mittels Flanschen

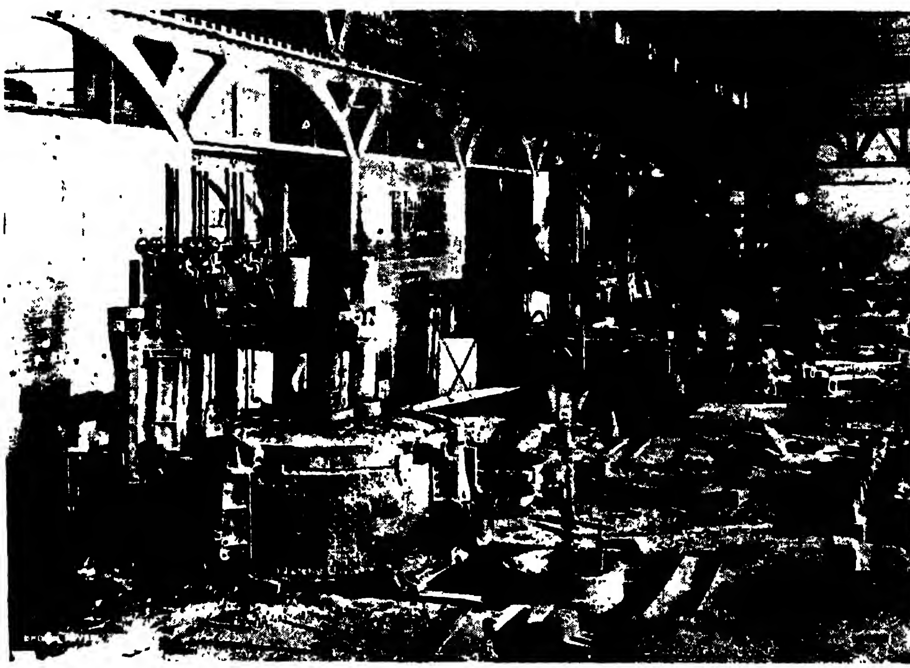

Abb. 7.—20 t Stahlofenanlage.

verstärkt sind. Das ganze Gehäuse wird häufig mit Aluminiumfarbe angestrichen, um die Strahlung auf ein Mindestmass zurückzuführen. Besonders sorgfältig sind die Türen gebaut, um die Glühkammer möglichst dicht zu halten. Die metallischen Widerstände, welche als Heizelemente dienen, sind gegossen, gewalzt oder gezogen und können im Ofen je nach Erfordernis beliebig angeordnet werden, entweder in Form von Bändern oder in Gestalt von flachen Gittern und Runddrähten, aber auch als Spulendraht. Die Regulierung der zugeführten elektrischen Leistung erfolgt bei einzelnen Fabrikaten durch Parallel-, Serien- und gemischte Schaltung, auch

teilweise durch Abschaltung der einzelnen Widerstandselemente, wenn nicht Anordnung eines Reguliertransformators oder eine ähnliche Einrichtung zwecks kontinuierlicher Regelung vorgesehen wird. Die maximalen Betriebstemperaturen für Glühöfen betragen vorläufig ca. 1 000°, doch sind Versuche zu einer entsprechenden Erhöhung dieser Temperaturgrenze auf 1 200°C und noch mehr im Gange.

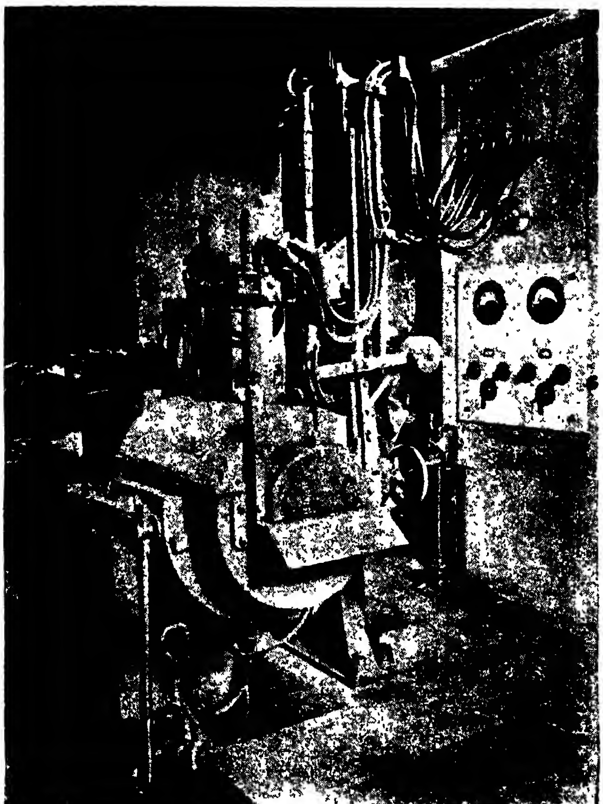

Abb. 8.—Silberschmelzofen. Fassungsraum 300 kg.

Das Anwendungsgebiet ist äusserst vielfältig, so werden z.B. in allen Industrien, wo das zu behandelnde Material nach dem Fabrikationsprozess innere Spannungen aufweist, Glühöfen zum Ausglühen des Materials benötigt. Die Glühöfen finden weiters Verwendung als Härteöfen zum Erwärmen von Werkzeugen, als Anlassöfen, wenn es sich darum handelt, gehärtete Werkzeuge, gehärtete Stahlfedern etc. neuerdings auf eine genau vorgeschriebene Temperatur zu bringen, als Emailöfen zum Emaillieren von Blechgeschirr,

Blechtöpfen, Blechkannen etc., als Brennöfen zum Brennen von keramischen Materialien und zum Glasieren. Auch bei der Herstellung von Aluminium, Kupfer und Messing werden Glühöfen verwendet, ebenso auch in der Glasindustrie, besonders der Glühlampenindustrie, in der Erzeugung von Glaslinsen, Kristallglas etc., also überall dort, wo genau vorgegebene Temperaturen erreicht und über der gesamten Werkstückoberfläche erhalten werden müssen. Das Glühen von Eisen und Stahl wurde bis vor wenigen Jahren in mit Brennstoff gefeuerten Öfen vorgenommen, man wandte sich aber sofort dem Glühofen zu, als die Forderung nach genauer und einheitlicher Wärmebehandlung dieser Metalle für den Wettstreit auf dem Arbeitsmarkte massgebend waren. Ein wertvoller Gesichtspunkt für die Verwendung der elektrischen Glühöfen ist nebstbei der, dass die Nachtenergie entsprechend herangezogen werden kann. Der Ofen wird am Abend eingeschaltet, mittels Zeitschalter zu einer bestimmten Morgenstunde automatisch abgeschaltet und kann dann während der Tageszeit für andere Zwecke verwendet werden.

Bezüglich der Wirtschaftlichkeit der Elektro-Glühöfen gegenüber den bisher verwendeten gas- und ölgefeuerten Öfen muss gesagt werden, dass die Beheizung durch den elektrischen Strom wohl teurer als die Brennstoffbeheizung kommt, dass sich ein richtiger Vergleich der Wirtschaftlichkeit aber erst bei Berücksichtigung sämtlicher massgebenden Faktoren erstellen lässt und dass die etwas höheren Stromkosten oft reichlich durch qualitätsverbessernde Arbeitsweise des Elektro-Ofens weitaus aufgehoben werden.

Für bestimmte Glühzwecke zieht man den gewöhnlichen Elektro-Muffelöfen elektrische Salzbadöfen vor. Es sind dies Öfen, in denen sich eine Salzschmelze befindet, welche stromdurchflossen ist und gleichzeitig als Wärmemittel dient. Der geringen Grösse des Badwiderstandes entsprechend ist ein sehr nieder gespannter Strom mit jedoch verhältnismässig grosser Stromstärke erforderlich. Ähnlich wie bei der elektrischen Punkt- und Stumpfschweiss maschine wird daher die Netzspannung durch einen besonderen Transformator auf die niedrige Ofenspannung transformiert. Durch Zu- und Abschaltung von Wicklungen auf der Primärseite des Transformators wird dessen Übersetzungsverhältnis entsprechend geändert, so dass dem Salzbad die erforderliche Niederspannung zugeführt werden kann. Der Salzbadofen gibt eine schnelle, vor allem besonders gleichmässige Erwärmung des Glühgutes, so das bei diesem Ofen in seiner Eigenschaft als Härteofen ein Materialausschuss ebenso wie beim Nieterhitzer ausgeschlossen ist.

Es soll noch die ausgedehnte Anwendung der elektrisch erzeugten Wärme für die Trocknung von Lacken, Farben und anderen Schutzüberzügen erwähnt werden, die in elektrischen Trockenöfen durchgeführt werden. Solche Öfen haben einen verhältnismässig kleinen Umfang und können überall aufgestellt werden. Das Werkstück wird in diesen Öfen hauptsächlich durch strahlende Wärme erhitzt, was auf die Qualität des Produktes von entscheidendem Einfluss ist. Es ist bei solchen Öfen auch möglich, eine gewissenhafte Kontrolle über die jeweils herrschende Temperatur und über die Dauer der Trocknung vorzunehmen, womit die Qualität des Endproduktes sichtlich beeinflusst werden kann. Aus diesem Grunde gewinnt der Elektro-Trockenofen in der Email-Industrie immer mehr an Bedeutung.

Die nachstehenden Bilder (Abb. 9 und 10) zeigen verschiedene Ausführungen moderner Elektro-Glühöfen. Dass die Elektrizität auch auf diesem Gebiete in Oesterreich siegreich Einzug hält, beweist der Umstand, dass für den Anschluss von Glüh- und Anlassöfen bisher bereits 3 100 kW, für den Anschluss der Trockenöfen 1 300 kW und für Anlass- und Zinnbäder 750 kW erforderlich sind.

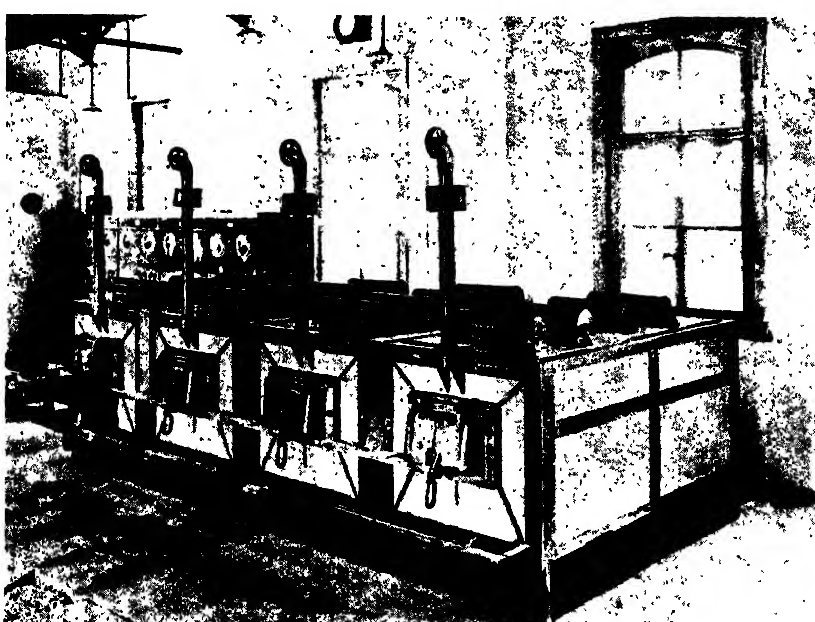

Abb. 9.—Elektro-Glühofenanlage, 4 Öfen je 25 kW Leistung, Glühraumtemperatur bis 800°C, nutzbarer Glühraum jedes Ofens ca. 1 800 x 500 x 300 mm.

Weitere Anwendungsmöglichkeiten der Elektrizität als Wärmequelle.—Ausser den bereits geschilderten Anwendungsmöglichkeiten der Elektrizität als Wärmequelle gibt es noch eine Unzahl weiterer Anwendungsgebiete, doch ist es mit Rücksicht auf den engen Rahmen dieser Abhandlung unmöglich, auch nur annähernd alle weiteren Möglichkeiten zu besprechen. In der Textilindustrie, in speziellen Werkstättenbetrieben, wie beispielsweise beim Anwärmen von Radreifen, bei der elektrischen Lufterhitzung, zur Apparateheizung in der Lebensmittelindustrie, wofür bisher 300 kW

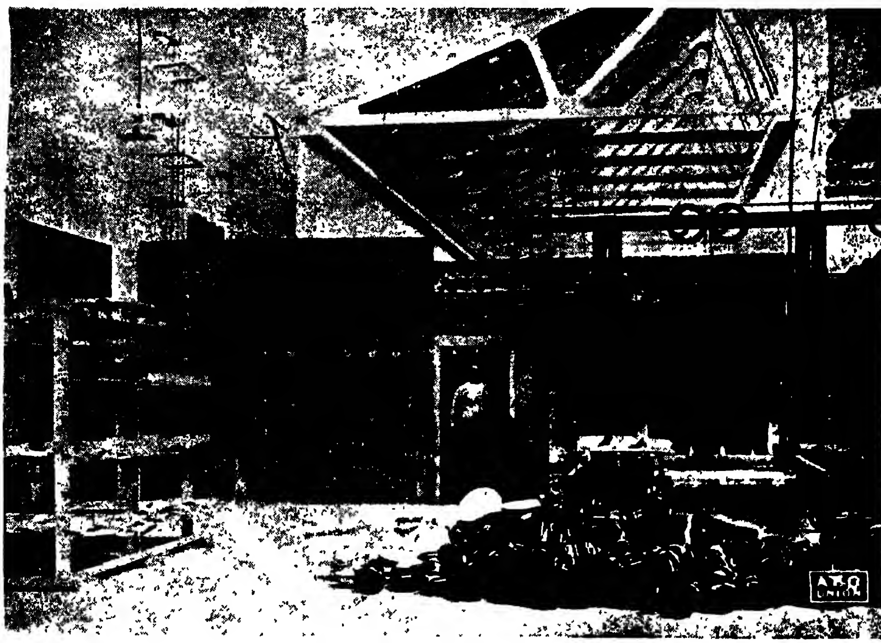

Abb. 10.—Glühofen in einem modernen Emaillierwerk.

Anschlusswert erforderlich sind, in der Oelindustrie, beim Schmelzen von Quarz, bei der Verflüssigung des Kohlenstoffes, beim Zementbrennen, beim Beheizen von Arbeitsmaschinen, Geräten und Werkzeugen deren Anschlusswert bereits 1 500 kW überschreitet, überall hier wird die Elektrizität als Wärmequelle verwendet, die mit Rücksicht auf ihre ungezählten Vorteile nunmehr ihren Siegeslauf in Gewerbe und Industrie angetreten hat.

RÉSUMÉ

Following on the development of the water-power of Austria, in which the authorities, both national and local, and industry generally have co-operated energetically, the country has begun to consider seriously the utilisation of electricity in heating processes. Beginning in a small way, Austrian industries

have, as far as economic conditions would permit, adopted electricity as a method of heating until now its use is firmly established in many directions. Electricity is now used for heating water, raising steam, drying moulds, heating rivets, welding, for smelting and reverberatory furnaces, and in drying ovens. Further possibilities for its use are opening out in many other trades, *e.g.*, textiles, general workshops, the oil industry, quartz melting, the liquefaction of carbon dioxide, for cement kilns, also for the heating of various machines and tools, etc.

The employment of electric heating has allowed methods and processes to be introduced which without it were either impossible or very expensive—electric welding is an outstanding instance—and by saving labour and energy has reduced costs of production. It has also reacted favourably on the running of power stations, as the consumption of current during the night has greatly improved the daily load curve and has thus increased the output. The use of electricity for heating has caused the capacity of many central stations to be increased, as is shown by the figures quoted below. Where possible the total net increase in capacity has been ascertained of all Austrian power stations due to the installation of new electric equipment or the remodelling and electrification of old plant. The additional loads connected for heating purposes during the last few years amount to:

Hot water heaters and storage	3 600	kW.
Steam boilers	17 000	,,
Rivet heaters	800	,,
Arc welding plant	2 100	,,
Spot and seam welding machines	400	,,
Smelting furnaces	27 300	,,
Reverberatory furnaces	3 100	,,
Drying ovens	1 300	,,
Tin baths	750	,,
Heating of process machines	1 500	,,
Cooking and food-heating appliances...	300	,,

LES CAMIONS À GAZOGÈNES

(SUCTION GAS PRODUCERS FOR MOTOR VEHICLES)

COMITÉ NATIONAL DU PÉTROLE

J. AUCLAIR

Paper No. K2

CONTENTS

L'emploi des gazogènes pour l'alimentation des moteurs de véhicules lourds soulève des questions à la fois techniques et économiques. Il est depuis longtemps démontré qu'il est possible de faire fonctionner un moteur de camion au gaz pauvre à la condition de réaliser une épuration suffisante du gaz: dans plusieurs expositions de voitures automobiles, il y a de quinze à vingt ans, ont figuré de tels groupes moteurs présentés en dehors d'un camion. Le véritable problème est de donner à l'équipement, gazogène moteur, la légèreté, la simplicité et le haut rendement nécessaires pour une exploitation économique du véhicule ; d'où l'importance de l'analyse des dépenses d'exploitation d'un camion.

Il est difficile de donner à cette analyse une généralité entière, parce qu'elle dépend du rapport entre le prix de revient de la construction et celui des combustibles. Il est possible toutefois de préciser dans quelques tableaux de chiffres les bases de la solution. Cette méthode a un avantage ; les conclusions que l'on en déduit ne s'appliquent pas seulement à des camions équipés à l'aide d'un gazogène mais à l'emploi de tout autre système de moteur.

On va donc étudier ***comment varient les dépenses d'exploitation d'un camion lorsqu'on substitue au moteur à essence un système de propulsion comportant l'emploi d'un autre combustible.***

Le moteur à combustion interne utilisant les carburants dérivés du pétrole est arrivé aujourd'hui à un haut degré de perfection

grâce à la multiplication des travaux expérimentaux, parmi lesquels ceux de l'Ecole anglaise et en particulier les travaux de Ricardo tiennent une grande place: il est difficile de trouver un moteur dont le poids au cheval soit moindre. Des combustibles pratiquement utilisables, l'essence de pétrole est celui qui possède l'énergie potentielle la plus élevée. Il est donc malaisé de substituer à l'essence un autre combustible sans alourdir l'équipement moteur et l'approvisionnement en combustible correspondant à une journée de service ; d'où le problème.

Une portion x seulement des dépenses d'exploitation d'un camion est affectée à l'achat du combustible, le reste, soit $(1 - x)$ correspondant aux frais d'amortissement, d'entretien, de garage et de main-d'oeuvre. Supposons qu'à la suite de la substitution d'un équipement à un autre la capacité de transport du camion soit réduite et qu'il faille $(1 + \alpha)$ camions pour faire le service que faisait précédemment un seul de ces véhicules, mais que par contre la dépense en argent pour le combustible soit réduite d'une fraction y. Les frais d'exploitation pour le même travail de transport deviendront

$$(1 - x)(1 + \alpha) + x(1 + \alpha)(1 - y)$$

et pour qu'ils ne dépassent pas leur valeur primitive il faut que y ait au moins la valeur données par l'équation

$$(1 + \alpha)(1 - xy) = 1.$$

Il est facile de dresser un tableau donnant pour tout couple de valeurs de x et de α la valeur limite y correspondante. Il donne pour toute valeur de la réduction de puissance l'économie compensatrice.

I.—RÉDUCTION DE CAPACITÉ DE TRANSPORT ET ÉCONOMIE COMPENSATRICE

α	0,25	0,30	0,35	0,40	0,45	0,50	0,55
0,05	0,19	0,16	0,13	0,12	0,10	0,09	0,09
0,10	0,36	0,30	0,26	0,23	0,20	0,18	0,17
0,15	0,52	0,43	0,37	0,33	0,29	0,26	0,24
0,20	0,66	0,56	0,48	0,42	0,37	0,33	0,30
0,25	0,80	0,67	0,58	0,50	0,44	0,40	0,36
0,30	0,92	0,77	0,66	0,58	0,51	0,46	0,42
0,35		0,86	0,74	0,65	0,58	0,52	0,47
0,40		0,95	0,82	0,72	0,64	0,57	0,52

On voit que pour une perte de capacité de transport un peu importante, aucune économie de combustible ne peut faire compensation. Encore n'a-t-on pas tenu compte du fait que la transformation de l'équipement moteur peut accroître le coût du camion, par suite le poste dépenses d'amortissement et d'entretien. Dans le cas des gazogènes toutefois, l'influence est faible: le prix du gazogène est à coup sûr compris entre 0,15 et 0,25 de celui du camion, il y aurait pour en tenir compte à multiplier x par un facteur compris entre 0,97 et 0,95, le résultat serait peu modifié. Mais il n'en serait pas de même si l'on appliquait le même mode de calcul à l'étude d'une transformation coûteuse du camion, telle que son équipement pour la propulsion électrique à l'aide d'accumulateurs.

Au taux de l'économie de combustible chiffrée globalement en argent dans le tableau I correspond une valeur maxima de l'unité de poids de celle-ci; elle dépend du rapport c des consommations spécifiques obtenues avec le combustible de remplacement et avec l'essence et du rapport v des valeurs argent de l'unité de poids des deux combustibles. On a

$$y = 1 - cv.$$

c étant généralement supérieur à 1 et v inférieur à ce même nombre. Un tableau peut comme plus haut traduire en chiffres cette relation.

II.—ÉCONOMIE, CONSOMMATION SPÉCIFIQUE ET PRIX DU COMBUSTIBLE

c	v						
	0,15	0,20	0,25	0,30	0,35	0,40	0,45
1,00	0,85	0,80	0,75	0,70	0,65	0,60	0,55
1,25	0,81	0,75	0,69	0,62	0,56	0,50	0,44
1,50	0,78	0,70	0,63	0,55	0,48	0,40	0,33
1,75	0,74	0,65	0,56	0,48	0,39	0,30	0,22
2,00	0,70	0,60	0,50	0,40	0,30	0,20	0,10
2,25	0,66	0,55	0,44	0,33	0,21	0,10	—
2,50	0,63	0,50	0,38	0,25	0,13	—	—

L'usage de ces tableaux est immédiat s'agit-il de remplacer dans un camion dont la dépense en essence représente 40 pour cent des frais d'exploitation, le carburant essence par un autre combustible; le tableau I nous apprend que, ce combustible étant le charbon de bois qui entraine une perte de puissance de 20 pour cent et une consommation en poids qui approche du double, l'économie en argent sur la dépense de combustible doit atteindre au moins 42 pour cent pour que la substitution soit possible, puis le tableau II donne pour la valeur

correspondante du rapport des prix des deux combustibles 0,29. Cette valeur ne peut d'ailleurs pas être atteinte, car il faut ménager une certaine marge de profit qui détermine l'exploitant à faire la transformation de son matériel. De ce point de vue il ne parait pas exagéré de dire que le prix du charbon de bois, à égalité de poids, doit être abaissé à 0,20 de celui de l'essence. Avec ces bases techniques qui correspondent sensiblement aux conditions imposées aux exploitations françaises au cours de ces dernières annnées et, tenu compte de la majoration du prix de l'essence due aux droits fiscaux, on peut dire que le charbon de bois ne doit pas coûter beaucoup plus de 500 francs la tonne pour que la transformation des camions à essence en camions à gazogène soit réellement avantageuse.

Les mêmes raisonnements sont valables en Angleterre en ce qui concerne le rapport des prix des combustibles pour la discussion de la possibilité de l'emploi sur les camions de gazogènes à anthracite, dont le fonctionnement est satisfaisant comme l'ont montré les essais d'un camion Thornycroft qui a figuré dans les épreuves organisées en France. Les bases techniques seraient un peu différentes si l'on abordait le cas des camions à vapeur. Mais ces explications suffisent à montrer combien sont strictes les limites dans lesquelles les recherches du technicien sont enfermées.

Cela tient, nous le répétons, à ce qu'au point de vue de la puissance massique, c'est-à-dire réalisable avec l'unité de poids de matériel et d'approvisionnement et de la commodité d'emploi, l'essence de pétrole est le meilleur combustible existant. Seuls peuvent lui être comparés des carburants composés avec les produits légers de la distillation des houilles et les alcools, mais à l'exception des benzols, ces carburants n'étaient pas jusqu'à aujourd'hui produits en quantités importantes.

La possibilité au point de vue économique, de substituer un combustible à l'essence est conditionnée par deux faits: la perte de capacité de transport résultant de la transformation du matériel et le prix du combustible. Ils doivent être examinés successivement.

La perte de capacité de transport peut tenir à des causes diverses; impossibilité avec le nouveau combustible de maintenir la puissance du moteur, d'où réduction de la vitesse de marche du camion en particulier dans les côtes ou bien limitation de la charge qu'il transporte ; poids de l'équipement moteur et de son approvisionnement qui vient en déduction du poids transporté; suggestions d'entretien qui immobilisent le véhicule et le personnel pendant une partie de la journée.

Il convient de remarquer que le poids du combustible intervient peu tant que le moteur reste un moteur à combustion interne Un camion de 3,5 à 4 tonnes de port utile consomme environ 30 litres d'essence aux 100 kilomètres, c'est-à-dire par journée, en cas de service intensif. C'est un peu moins de 25 kilogrammes; à supposer que le poids de l'approvisionnement double avec un gazogène ou même triple pour tenir compte de la dépense d'eau que font certains appareils, la surcharge n'atteint encore que 50 kilogrammes, valeur bein peu importante par rapport à la charge utile.

Mais il n'en est pas toujours ainsi, par exemple dans le cas de l'emploi du moteur à vapeur. Le poids de l'approvisionnement en combustible est sensiblement triplé, mais il faut y joindre le poids de l'eau qui, pour une journée de plein travail (100 kilomètres de parcours), ne peut guère être abaissé au-dessous de 800 à 900 kilogrammes. Un camion à vapeur qui ne trouverait pas un ravitaillement en eau tous les 20 ou 25 kilomètres perdrait, du fait de la surcharge en matières consommables pour la production de la force motrice, près de 25 pour cent de sa capacité de transport.

La question de la surcharge due à l'approvisionnement se trouvant ainsi écartée—au moins dans le cas des camions à gazogènes—restent à examiner les autres causes de réduction de la capacité de transport.

La perte de puissance du moteur a joué un grand rôle dans les premières expériences vers 1922. Une politique d'opportunité avait conduit à faire les premiers essais d'application des gazogènes à la propulsion des camions en transformant des camions à essence dont le moteur était conservé avec le minimum de modifications. La perte de puissance était énorme, de plus de 30%.

La puissance d'un moteur à combustion interne est toutes choses égales d'ailleurs—sauf dans le cas de certains carburants spéciaux—sensiblement proportionnelle à la puissance calorifique de la cylindrée. Celle-ci a été trouvée égale dans le cas des moteurs de camions alimentés par gazogène à 600 calories au mètre cube, chiffre moyen résultant du dépouillement de 25 essais. Comme d'après Ricardo la composition de la cylindrée qui avec l'essence donne la meilleure consommation spécifique correspond à un pouvoir calorifique de 914 calories, la réduction de puissance serait supérieure à 30 pour cent s'il n'était pas possible d'obtenir une certaine compensation pour l'accroissement du taux de compression, possible avec le gaz de gazogène. Mais on ne peut pas aller bien

loin dans cette voie et le gain ne dépasse pas 8 pour cent si même il atteint ce chiffre. Il était difficile en cet état de la technique de ramener au-dessous de 20 ou 25 pour cent la perte de puissance des camions à gazogènes.

Avec la perspective d'une extension de l'emploi de ces véhicules la situation s'est modifiée parce que les constructeurs ont envisagé la création de moteurs spéciaux dans lesquels un accroissement de puissance est obtenu par une augmentation de l'alésage, qui peut être réalisée par la seule transformation du bloc-cylindres, sans modifications des autres organes du moteur ni changement sensible de son poids. Cette évolution a même permis de revenir un peu en arrière dans la voie de l'augmentation du taux de compression qui n'était pas sans inconvénients pour la conservation et le bon fonctionnement des organes d'allumage de construction usuelle.

Il est intéressent de donner un tableau qui permette de suivre cette évolution. Toutefois il est difficile de le remplir: l'évolution ne marche pas du même pas chez tous les constructeurs, il est parfois difficile d'obtenir des renseignements numériques précis, les moyennes enfin peuvent être notablement changées selon qu'on regarde comme différents ou comme identiques des équipements qui ne se distinguent que par des détails secondaires et, que par suite, on utilise plusieurs fois ou une seule leurs caractéristiques dans l'établissement des moyennes. Le tableau que l'on va lire est établi en prenant pour base seulement les appareils nettement différentiés qui ont pris part aux épreuves officielles et qui ont été mesurés d'une manière précise. Il renferme la pression moyenne indiquée qui a été calculée en partant de la puissance disponible sur l'arbre et en admettant pour la valeur du rendement mécanique du moteur 0,75.

III.—ÉVOLUTION DES CARACTÉRISTIQUES DES ÉQUIPEMENTS: CYLINDRÉE, TAUX DE COMPRESSION, PRESSION MOYENNE INDIQUÉE

Caractéristiques	Année des épreuves			
	1922.	1923.	1925.	1927.
Cylindrée totale en litres ..	5,48	5,49	5,54	5,65
Taux de compression ..	4,50 ?	5,99	5,91	5,80 6,14
Pression moyenne indiquée en kg./cm²	3,90	5,38	5,33	4,96

Le taux de compression est donné sous réserves en 1922 et il en est fourni deux valeurs en 1927 : en 1922 il n'a pas été procédé à une mesure directe du volume de la chambre de compression; le

premier chiffre de 1927 correspond à 10 des équipements, le second à l'ensemble, c'est-à-dire à 12 équipements, mais pour les deux complémentaires le taux de compression est particulièrement élevé et, pour l'un même, de détermination doûteuse.

Sous le bénéfice de ces observations on voit se dessiner après un effort très marqué en 1923 vers une utilisation élevée de la cylindrée une tendance à *demander plutôt la conservation de la puissance du moteur à une légère augmentation de la cylindrée* combinée avec une valeur assez faible de la pression indiquée. Il ne paraît pas doûteux que dans cette voie on parvienne à construire des camions à gazogènes de tout point comparables comme puissance et par suite comme vitesse de marche aux camions à essence. Plusieurs constructeurs ont présenté des types de cette classe.

Mais il n'en subsiste pas moins du fait du poids du gazogène et de ses accessoires un handicap notable au point de vue de la capacité de transport pour le camion pourvu de cet appareillage. Voici les poids constatés.

IV.—POIDS DES GAZOGÈNES ET DE LEURS ACCESSOIRES.

Poids des appareils en kilogrammes.	Année.		
	1923.	1925.	1927.
Poids minimum	313	290	202
Poids maximum	530	394	500
Poids moyen	414	351	338

Le poids moyen de l'équipement tend donc à se fixer aux environs de 350 kilogrammes. Il est sensiblement le même pour les camions de 3,5–4 tonnes et ceux de 5 tonnes; cela tient à ce que les deux types de véhicules, souvent munis d'équipements moteurs à peu près identiques, diffèrent surtout par la démultiplication qui donne aux camions lourds une vitesse moindre; ceux-ci de ce fait sont moins lourdement handicapés. La perte de capacité de transport peut ainsi varier de 7 à 12 pour cent.

Les poids extrèmes correspondent, en général, à des types de construction un peu spéciaux, ainsi en 1927 le gazogène pesant 202 kilogrammes est d'un très faible volume et construit entièrement en tôlerie, l'appareil pesant 500 kilogrammes est un type de construction un peu ancienne que l'on a muni après coup d'une enveloppe extérieure pour l'isoler du camion et de l'extérieur; mais cette même année 60 pour cent des appareils ont des poids assez voisins du poids moyen.

Il y a comme dans toutes les techniques de construction qui se perfectionnent *évolution vers un type définitif. Avec les combustibles*

à faible teneur en cendre et haute réactivité employés presque exclusivement aujourd'hui ce type est le gazogène à combustion renversée, sans injection de vapeur, avec épuration par filtration sur étoffe.

Les appareils du début en étaient, sauf un qui fut un peu un précurseur, fort différents. Leurs constructeurs s'étaient visiblement inspirés de deux directives: qu'il fallait d'une part organiser le plus complètement possible la récupération des chaleurs perdues pour obtenir des appareils d'une puissance massique élevée et qu'il était d'autre part indispensable de multiplier les épurations afin d'éviter les entrainements de poussières et de goudrons auxquels on attribuait alors une usure rapide du moteur. On a vu sur un même appareil triple récupération, par échauffement de l'air comburant dans un échangeur de chaleur spécial, par circulation de cet air et de la vapeur d'injection dans une double enveloppe entourant le foyer, par injection de vapeur et en même temps triple épuration à l'aide de deux filtres et d'un laveur rotatif imité des appareils Theisen. Dans bien des cas il y avait double lavage du gaz à l'aide d'eau, puis d'huile. Ces dispositifs fonctionnaient bien et ils ont eu leur heure d'opportunité, mais ils avaient l'inconvénient de rendre l'appareil de conduite plus délicate et d'imposer au chauffeur un travail d'entretien ennuyeux. Ils ont en grande partie disparu avec la combustion renversée et la filtration sur étoffe.

Celle-ci assure une épuration suffisante. Il a fallu admettre d'ailleurs que les craintes que l'on avait eues touchant l'endurance des moteurs à l'égard de l'usure résultant des impuretés véhiculées par le gaz étaient très exagérées: des expériences d'emploi poursuivies à fond par des industriels avertis ne les ont pas décelées. Les constatations faites au début dans cet ordre d'idées doivent donc être révisées. On peut penser même que la conservation des moteurs est plus facile avec le gaz pauvre qu'avec l'essence parce qu'avec ce dernier carburant il se produit nécessairement une altération progressive des huiles de graissage due à l'entrainement dans celles-ci de l'essence non brûlée: il parait impossible, en effet, qu'au cours d'un fonctionnement du moteur dans les conditions variées qu'entraine la propulsion d'un camion il ne s'intercalle pas de nombreuses périodes de marche avec excès d'essence.

Quoiqu'il en soit, voici un tableau qui donne une idée de l'évolution des types. On y a fait figurer en pour cent du total des appareils examinés le nombre des cas où l'on rencontre certaines dispositions. Il est établi comme le précédent en ne tenant compte que des types réellement distincts.

V.—ÉVOLUTION DES TYPES D'APPAREILS

Dispositions caractéristiques des équipements.	Année. 1922.	1923.	1924.	1926.
Combustion ascendante ou horizontale	80	83	25	38
Combustion renversée	20	17	75	62
Injection de vapeur	80	83	50	25
Echangeur de chaleur spécial pour récupération	20	83	25	0
Epuration du gaz par lavage à l'eau ou à l'huile	80	83	50	33
Epuration par filtration sur étoffe ou décantation simple	20	17	50	67

La tendance est nette et l'évolution serait encore plus apparente si au lieu du nombre des types d'appareils, c'était le nombre des camions munis de ces types qui figurait dans le tableau. Dans sa composition même subsiste un certain degré d'imprécision parce que les faits répugnent à une classification aussi brutale que celle qu'il suppose: par exemple, il est bien certain que si les organes spéciaux et distincts pour l'échauffement de l'air comburant ont disparu dans les matériels actuels, cet échauffement n'est pas entièrement abandonné comme tendrait à le faire croire le 0 de la dernière colonne: dans le plus grand nombre des appareils encore l'air comburant circule autour du foyer avant d'y pénétrer.

L'intérêt de cette évolution c'est qu'elle tend manifestement à une grande simplification dans la conduite et l'entretien des appareils: 1° une récupération élevée des chaleurs perdues avec l'injection abondante de vapeur qui lui doit être associée pour que la température du gazogène ne s'élève pas trop est une arme à double tranchant, car un gazogène trop refroidi est, au moment d'une reprise ou lorsqu'on aborde une côte, dans de mauvaises conditions de marche et peut être insuffisant. Il est donc nécessaire de prévoir un réglage au moins partiel, qui est une sujétion gênante pour un chauffeur peu mécanicien et occupé de la conduite de son camion. 2° Le nettoyage des épurateurs par voie humide nécessite un lavage à grande eau, le plus souvent tous les jours; c'est une opération laissant des traces malpropres. Les épurateurs à sec au contraire ne donnent comme résidus que de légères poussières, qu'il suffit d'éliminer de temps à autre en renversant le réservoir où elles se rassemblent. 3° La combustion renversée permet le rechargement du gazogène sans arrêter le moteur et sans qu'il y ait besoin d'employer une trémie fermée formant écluse, système peu compatible avec une introduction massive du combustible.

L'entretien des appareils établis dans ces conditions est des plus simples; il se réduit au décrassage de la grille, au rejet à l'extérieur des résidus du cendrier et du réservoir à poussières, et à l'allumage du gazogène. Cette opération dont on s'effrayait au début est devenue très rapide, comme le montre le tableau suivant déduit d'une centaine d'expériences, tableau dans lequel figurent pour cinq types d'appareils les durées de mises en route. Elles sont comptées de l'allumage du gazogène jusqu'à l'instant où la production de gaz est suffisante pour permettre au camion des se mettre en marche.

VI.—DURÉE MOYENNE DES MISES EN ROUTE AVEC DIVERS ÉQUIPEMENTS

Nature du gazogène—Combustible et procédé d'allumage.	Durée de mise en route en *m.* et *s.*
Gazogène à charbon de bois à combustion ascendante. Allumage par aspiration du moteur fonctionnant à l'essence	6*m*
Gazogène à bois à combustion renversée. Allumage par aspiration par ventilateur à main	6*m* 15*s*
Gazogène à charbon de bois à combustion renversée. Allumage par aspiration par ventilateur à main ..	6*m* 40*s*
Gazogène à charbon de bois à combustion ascendante. Allumage par soufflage par ventilateur à main ..	9*m* 20*s*
Gazogène à agglomérés de charbon de bois à combustion renversée. Allumage par aspiration par ventilateur à main	9*m* 40*s*

La mise en route des camions à gazogènes n'exige ainsi pas beaucoup plus de temps que n'en demande parfois celle d'un véhicule à essence dont le moteur est froid.

Par ailleurs un camion à gazogène couvre une distance de 50 kilomètres sans rechargement, distance portée au double avec des agglomérés denses. Des arrêts d'une certaine durée sont possibles sans autres précautions qu'un soufflage de 2 ou 3 minutes au départ. La conduite du véhicule est aussi facile et aussi simple que celle d'un camion à essence.

En un mot on peut dire que la main-d'œuvre supplémentaire est réduite au minimum: le court entretien du gazogène à la rentrée au garage, et que la capacité de transport du camion n'en est pas sensiblement réduite.

La simplification de l'entretien est due principalement au choix du procédé d'épuration, filtration sur étoffe, les deux autres caractéristiques, combustion renversée et fonctionnement sans injection de vapeur, lui sont dans une certaine mesure liées parce qu'il faut éviter rigoureusement tout dépôt de goudrons ou d'humidité qui viendrait colmater le filtre. Ces deux caractéristiques toutefois ne

correspondent pas aux meilleures conditions de marche au point de vue de l'économie et de l'utilisation de la cylindrée: on sait, en effet, qu'avec la combustion renversée le combustible déjà partiellement converti en cendres est en contact avec le gaz le moins riche en oxygène et que par suite la proportion d'imbrûlés est plus importante. D'autre part l'absence de vapeur entraine une diminution du pouvoir calorifique du gaz et une réduction, moindre à la vérité, mais encore notable du pouvoir calorifique de la cylindrée et par suite de l'utilisation du moteur.

Le tableau suivant donne la composition moyenne du gaz obtenu avec les divers types de gazogènes et de combustibles au cours des essais officiels qui ont eu lieu en 1927. Dressé en prenant les moyennes, colonne par colonne, il ne peut fournir de chiffres exactement concordants entre eux.

VII.—COMPOSITION ET POUVOIR CALORIFIQUE DU GAZ PENDANT LES ESSAIS FAITS EN 1927.

Type du gazogène et combustible.	Composition du gaz en % de							Pouvoir calorifique du gaz en gr cal. par m³
	CO^2	O	CO	H^2	C^nH^m	CH^4	Az	
Combustion renversée sans injection de vapeur—Bois	12,13	0,89	19,62	17,02	0,33	0,76	49,40	1.321
Combustion horizontale ou ascendante avec injection de vapeur—Charbon de bois	3,70	1,10	29,85	12,89	0,00	0,38	51,95	1.300
Combustion renversée sans injection de vapeur—Carbon de bois ou agglomérés de charbon de bois	1,27	1,31	30,72	5,69	0,00	0,20	61,75	1.077

Ces résultats montrent nettement l'influence de l'injection de vapeur: le gazogène est un peu froid, mais la forte proportion d'hydrogène donne un pouvoir calorifique plus élevé. Les mêmes phénomènes sont beaucoup plus accusés avec le bois: la forte teneur en eau de ce produit (eau d'humidification et eau de constitution) a les mêmes conséquences qu'une injection de vapeur excessive: l'allure du gazogène est très froide comme le marque la haute teneur en CO^2 par contre la grande quantité d'hydrogène et la proportion plus élevée de carbures relèvent le pouvoir calorifique à un taux intéressant. On a même atteint dans une expérience 1.500 calories au mètre cube.

Toute cette évolution est au fond de nature à réduire l'utilisation du moteur et du combustible. Or voici les consommations spécifiques constatées au cours des expériences poursuivies de 1922 à 1927. Pour les rendre comparables elles sont exprimées en poids d'un combustible fictif d'un pouvoir calorifique de 7.400 calories au kilogramme, les consommations spécifiques réellement observées ayant été réduites par le calcul.

VIII.—ÉVOLUTION DES CONSOMMATIONS SPÉCIFIQUES.

	Année des observations.			
	1922.	1923.	1925.	1927.
Consommations spécifiques en grammes par cheval heure	625	561	560	517

L'écart entre les chiffres donnés pour 1922 et 1925 s'explique par l'adoption d'un taux de compression notablement plus élevé que dans le cas des moteurs fonctionnant à l'essence. L'écart entre les chiffres de 1925 et de 1926 paraît tenir à un meilleur réglage de la carburation : l'excès d'air par rapport à la proportion correspondant à la combustion parfaite passe en effet de la première de ces deux années à la seconde de 13,2 pour cent à 5,21 pour cent.

Il est un renseignement toutefois qui figure dans aucun de ces tableaux, c'est la valeur de la puissance maxima que l'on peut demander aux groupes gazogène moteur. Il est, en effet, difficile de la déterminer au cours des essais au banc. Ceux-ci ont toujours une certaine durée pour permettre la mesure de la consommation spécifique et d'autres observations telles que l'étude des gaz du gazogène et de l'échappement; l'excès de chaleur dégagé dans le générateur dont les organes, gazogène proprement dit, épurateurs, réfrigérants, sont moins refroidis que sur la route, ne permet pas la marche à pleine puissance: les essais sont faits à une vitesse un peu réduite et à une puissance moyenne correspondant aux conditions de marche normales de la route. Force est donc de rechercher par une autre voie des renseignements sur la puissance maxima des véhicules.

On y est parvenu par des chronométrages de la vitesse des camions sur des côtes d'une pente accentuée, mais de faible longueur. Il est rationnel d'admettre, en effet, que les camions ne doivent pas fournir d'une manière continue leur puissance maxima, mais qu'il leur faut une certaine réserve de puissance permettant d'aborder sans réduction excessive de vitesse les parties difficiles de leurs

parcours. Le problème est d'ailleurs tout différent pour les tracteurs agricoles qui travaillent toujours à puissance maxima et leur équipement à l'aide de gazogènes doit être étudié dans d'autres conditions.

En côte la puissance nécessaire pour élever la masse du camion est facile à déterminer. Des considérations qu'il serait trop long de développer ici basées sur de nombreux essais portant sur le rendement organique de propulsion des véhicules automobiles conduisent à penser que la puissance du moteur dans le cas envisagé (marche à vitesse réduite) est obtenu en divisant par 0,65 la valeur de la puissance correspondant au travail d'élévation du poids du camion. Le tableau suivant donne les résultats des chronométrages en côte effectués en 1925 et 1927: il fait connaître la puissance développée par le moteur rapportée à la tonne de poids total du véhicule.

IX.—PUISSANCE MAXIMA EN CÔTE

Puissance en chevaux vapeur par tonne.	Année et conditions de la détermination. 1925 sur côte de 1.700 mètres à 5,85%.	Année 1927 sur côte de 280 mètres à 12%
Minima	1,76	2,86
Maxima	5,67	6,16
Moyenne	3,32	4,06

Il importe toutefois d'observer que les deux séries de déterminations ne donnent pas de résultats rigoureusement comparables: les résultats obtenus sont d'autant plus élevés que la côte est plus rapide et la distance sur laquelle on chronomètre plus courte; les chiffres de 1925 devraient être majorés. On obtient ainsi des puissances de 30 chevaux pour un camion pesant en charge 8 tonnes.

Cette analyse a eu pour objet de donner la sensation de l'évolution du camion à gazogène telle qu'elle apparaît au technicien par le dépouillement et la comparaison pièce à pièce des nombreux essais qui ont eu lieu. Dans l'impossibilité d'enfermer dans un court rapport les éléments qui ont servi de base à cette étude on a cherché à en donner une idée par des tableaux de moyennes *sans méconnaître ce qu'il y a de barbare dans un tel procédé.* La conclusion n'en est pas moins nette: *le camion à gazogène évolue vers un type de conception et de construction un peu différent du camion à essence, mais très simple et qui pourra rendre les mêmes services. Toutefois, en raison du poids de son équipement spécial, sa capacité de transport reste irréductiblement inférieure de 10% environ.*

Pour bien comprendre comment se pose dans le cas des gazogènes pour camions le problème né du prix du combustible, il faut tout d'abord examiner les conditions techniques auxquelles celui-ci doit satisfaire.

L'une a pour origine la grande activité que doit avoir la combustion. La section du foyer dans la région où elle se produit ne dépasse guère 10 à 12 décimètres carrés, d'autre part nous avons vu que la puissance à développer par le moteur atteint dans certains cas limites près de 50 chevaux (camion pesant 8 tonnes et rapport 6 de la puissance en chevaux au poids en tonnes) avec une consommation spécifique de l'ordre de 500 grammes; cela fait plus de 200 kilogrammes par mètre carré et par heure. C'est à égalité de surface une combustion au moins égale aux plus fortes combustions que l'on observe dans les gazogènes fixes. Comme les gazogènes de camions sont très petits dans toutes leurs dimensions, la zône de combustion se trouve réduite non seulement en section, mais encore en hauteur, de telle sorte que dans ces appareils l'intensité massique de la combustion, s'il est permis de parler ainsi, dépasse les plus fortes valeurs usitées.

Le combustible doit donc être très réactif, pour employer une expression créée en métallurgie en vue de désigner l'aptitude des cokes à la combustion. On sait que l'on rattache généralement cette propriété à la structure poreuse de la matière qui facilite la mise en contact du combustible et du gaz comburant et on la caractérise par la vitesse de réaction. Les combustibles jusqu'à maintenant employés dans les gazogènes sont en général dérivés du bois, et comme conséquence de cet origine très poreux, on ne s'est pas encore heurté à des difficultés résultant d'une réactivité insuffisante.

Cette qualité du combustible est *encore essentielle à un autre point de vue: pour faciliter les reprises*. Alors que les gazogènes fixes fonctionnent le plus souvent à allure constante et régulière, les gazogènes de camions doivent tolérer un régime essentiellement variable parce que la propulsion du véhicule exige du moteur une puissance fonction de l'état et de la déclivité de la route. Il faut même que le gazogène puisse demeurer en veilleuse pendant les arrêts qu'impose le service du camion tout en restant en état de propulser presque immédiatement le camion. Or on sait que la production d'un gaz de composition convenable implique une certaine température de la zône de combustion; le gazogène se refroidit pendant les périodes de marche à puissance réduite

et à plus forte raison pendant les arrêts; pour que les reprises ne soient pas molles et lentes il faut donc que l'activité de la combustion soit assez active non seulement pour fournir la quantité de gaz appelé au moteur, mais encore pour relever presque instantanément la température de l'appareil.

Cette considération explique peut-être l'abandon des dispositifs de récupération complète des chaleurs perdues, car il est bien évident que seules les chaleurs perdues par refroidissement externe, à l'exclusion de celles employées à produire des réactions endothermiques de nature à enrichir le gaz, peuvent servir à un réchauffage rapide de l'appareil.

On a employé cependant avec succès dans les gazogènes transportables l'anthracite combustible peu réactif et des agglomérés de charbon de bois, lesquels bien que préparés en vue d'une combustion facile, sont moins réactifs que le charbon de bois. Ces combustibles toutefois compensent leur infériorité au point de vue de la réactivité par deux qualités; une grande densité et un classement très régulier en petits éléments de mêmes formes et dimensions. La grande densité et le classement permettent de constituer une charge du gazogène essentiellement propre à une circulation uniforme de l'air comburant, de telle sorte que le plus grand poids de combustible entrant en réaction compense dans une certaine mesure sa faible réactivité spécifique. Cependant avec ces combustibles les mises en feu initiales et les reprises des gazogènes sont un peu moins faciles.

Une faible teneur en cendres des combustibles est également une qualité requise en raison de la dimension réduite des foyers et de la généralisation de la combustion renversée. Il est bien clair, en effet, que l'activité de la combustion ne peut être que ralentie dans un foyer encombré de résidus; l'effet est, comme nous l'avons dit déjà, particulièrement marqué dans le cas des gazogènes à combustion renversée dans lesquels la charge est apauvrie progressivement en éléments combustibles. Par ailleurs les secousses auxquelles est soumis le générateur par la marche du camion sont de nature à conférer aux gazogènes transportables quelques-unes des qualités des gazogènes fixes à élimination mécanique des cendres par grille tournante, par exemple. On s'est fait toutefois quelques illusions à ce point de vue puisque tous les gazogènes transportables ont pu fonctionner au banc sans difficultés spéciales tenant à l'immobilité du gazogène.

Quoiqu'il en soit les gazogènes transportables n'ont utilisé jusqu'à maintenant que des combustibles à faible teneur en cendres et nous croyons que certaines modifications des appareils seraient à envisager pour que l'on puisse y employer des combustibles artificiels obtenus à l'aide de déchets de bois, de semi-cokes, etc., combustibles tenant 10% de cendres ou même plus.

La fusibilité des cendres n'a donné lieu jusqu'à maintenant à aucune observation sauf dans le cas de certains gazogènes à tuyères pour l'injection de l'air, dans lesquels des accidents de fusion de tuyères, après empatement de celles-ci, par le mâchefer, ont été observés. Cette inocuité tient à la faible quantité et à la haute température de fusion des cendres des combustibles employés, mais dans ce cas aussi l'emploi de combustibles d'autres origines peut conduire à des modifications des appareils en vue d'une limitation de la température du foyer, par exemple à un retour à l'injection de vapeur.

Le classement du combustible, c'est-à-dire sa mise méthodique en éléments de dimensions et même de formes déterminées, *a une importance extrème pour la bonne marche des appareils.* C'est une opération de préparation initiale, mais il faut que la qualité acquise subsiste pendant les manutentions et même pendant toute la durée de la combustion. Le combustible doit donc avoir une résistance mécanique élevée et brûler par couches concentriques de la surface au centre sans altérations résultant d'une fusion ou d'un éclatement des éléments. Le charbon de bois qui possède une haute réactivité et une faible teneur en cendres se comporte mal au point de vue de la résistance mécanique. Il est bien possible de le concasser en éléments de dimension optima, mais cette opération ne s'effectue pas sans une abondante production de poussier. Une portion importante du combustible se transforme également au cours des manutentions en poussier mal utilisable. Toutes ces pertes accroissent le prix réel du combustible. De là résulte le grand intérêt de la fabrication d'agglomérés de charbon de bois, qui ayant une réactivité et une teneur en cendres encore suffisantes possèdent en outre les qualités physiques de résistance mécanique et de permanence de forme indispensables.

Cette fabrication permet, en outre, de reprendre et d'utiliser le poussier comme d'employer pour la préparation du charbon de bois les déchets de l'industrie du bois et les rémanants ou déchets de l'exploitation forestière.

L'emploi systématique d'agglomérés aurait un autre intérêt qui n'est pas moindre; *il permettrait d'envisager l'utilisation dans les gazogènes d'un combustible standard que l'on puisse trouver partout identique à lui-même.* Il ne faut pas croire que l'on peut brûler dans un gazogène donné toute sorte de combustibles: le foyer doit être dimensionné en tenant compte de la densité et de la réactivité du combustible; l'allure optima de l'appareil dépend de la teneur en eau du combustible, car l'eau qui imprègne celui-ci a les mêmes effets qu'une injection de vapeur: on a vu par exemple que l'allure des gazogènes à bois demeurait froide. L'instabilité de la teneur en eau est donc un grave défaut pour le combustible, or elle caractérise précisément le charbon de bois à l'état naturel: c'est un corps qui se charge facilement d'humidité au contact de l'air; les agglomérés, au contraire, peuvent être préparés avec une surface légèrement glacée qui les rend dans une large mesure insensibles à l'action de l'humidité atmosphérique.

Un autre élément que permet de régler l'emploi d'un combustible standard est la teneur en matières volatiles du combustible—nature et quantité. Les procédés d'épuration employés dans le plus grand nombre des appareils actuels et qui consistent dans la filtration du gaz sur étoffe après un simple refroidissement sont incompatibles avec la présence de traces notables de goudrons qui colmateraient le filtre; il faut donc que les matières volatiles du combustible soient de nature telle que la gazéification ne produise pas de goudrons condensables.

Les combustibles artificiels ouvrent la voie enfin à l'emploi de combustibles activés artificiellement ou enrichis par absorption de gaz combustibles. On peut donc dire qu'en dehors du fait qu'ils rendent possible la standarisation de l'approvisionnement en combustibles de qualité optima, ils ouvrent de nouvelles possibilités de progrès.

Haute réactivité—Faible teneur en cendres—Cendres peu fusibles—Résistance mécanique élevée assurant la conservation pendant les transports de l'invariabilité de forme dans le gazogène—Classement rigoureux—Indifférence à l'humidité atmosphérique—Matières volatiles ne donnant pas de goudrons pendant la gazéification—Constances de ses propriétés—telles sont les qualités que doit posséder le combustible pour gazogènes transportables. On ne peut guère les trouver réunies que dans des combustibles artificiels spécialemen préparés.

Des tentatives diverses ont été faites pour la création de tels combustibles, certaines ont abouti déjà à des résultats remarquables au point de vue technique, d'autres autorisent de sérieuses espérances, mais ces produits restent encore d'un prix élevé. Le charbon de bois et le bois plus exceptionnellement sont encore employés dans de nombreux appareils. Voici au surplus pour les essais contrôlés en 1927 le pourcentage d'emploi et la composition moyenne des combustibles.

X.—COMBUSTIBLES EMPLOYÉS PENDANT LES ESSAIS CONTRÔLÉS EN 1927

Nature du combustible.	Bois.	Charbon de bois.	Agglomérés.
Pourcentage d'emploi	24	46	30
Humidité en pour cent du poids . .	14,4	5,83	4,17
Cendres do. . . .	0,66	3,10	3,59
Matières volatiles do. . .	67,84	5,75	2,65
Hydrogène do. . .	5,03	2,32	1,81
Carbone fixe do. . .	43,47	82,82	88,17
Pouvoir calorifique supérieur en calories par kilogramme . .	4 205	7.293	7.691

L'humidité a été déterminée par chauffage du combustible à l'étuve à 105°, les matières volatiles par distillation dans un creuset fermé avec cheminée. La teneur en matières volatiles dans le cas du bois comprend donc la teneur en eau de constitution.

Les agglomérés employés sont très voisins du combustible type tel que nous venons de le définir. En quoi le bois et le charbon de bois s'en écartent-ils?

Le bois a été employé à peu près exclusivement à l'état de bois étuvé découpé en morceaux réguliers; les essais faits pour l'emploi de bois tout venant n'ont pas donné de résultats pleinement satisfaisants. C'est un combustible très propre, d'un emploi commode, donnant par sa haute réactivité et la richesse calorifique du gaz produit un fonctionnement pleinement satisfaisant du moteur. Il a contre lui un encombrement en volume et en poids sensiblement double, le grand lest de vapeur qu'entraine le gaz qui nécessite une réfrigération spéciale pour sa condensation, le danger de pollution rapide du moteur par les goudrons en cas de marche irrégulière du gazogène. Le bois étuvé et découpé a subi d'ailleurs une préparation qui porte son prix de revient sensiblement au même taux que celui du charbon de bois.

Les deux défauts essentiels du charbon de bois sont sa friabilité et sa grande aptitude à absorber l'humidité de l'air. Sa friabilité,

par le déchet qu'elle entraine augmente sensiblement le coût du combustible. Elle a de plus l'inconvénient d'en faire un combustible qui souille d'une poussière noire le véhicule et son conducteur; cette particularité est l'une des causes de la répugnance des conducteurs de camion à l'emploi des gazogènes à charbon de bois. Peut-être serait-elle atténuée par la délivrance du combustible en sachets de papier fermés.

Il est possible maintenant de donner une vue d'ensemble de la question.

Le camion à gazogène peut rendre sensiblement les mêmes services que le camion à essence.

Toutefois il reste définitivement handicapé par une perte de capacité de transport de 10 pour cent environ. Cela ne lui permet la concurrence avec le camion à essence qu'à condition qu'il y ait un bénéfice marqué sur le coût du combustible.

Des combustibles pratiquement suffisants, bois, charbon de bois, agglomérés de charbon de bois, anthracite ont été employés.

Mais la vulgarisation du camion à gazogène ne peut guère être conçue possible sans la création de combustibles artificiels spéciaux permettant un approvisionnement standard.

Dans ces conditions, la question du prix du combustible se précise :

Ce combustible doit être autant que possible un combustible spécial standard; provisoirement le bois, le charbon de bois, des agglomérés usuels de charbon de bois, etc., l'anthracite même de bonne qualité peuvent lui être substitués.

Les conditions techniques de fonctionnement des groupes gazogène moteur lorsque l'évolution actuellement en cours sera terminée, permettent d'escompter une perte de capacité de transport inévitable de 10 pour cent et un rapport de consommation spécifique en poids de 1,50 à 1,75. Il en résulte que le prix au poids du combustible de remplacement de l'essence peut être au maximum de 0,50 à 0,60 pour cent de celui de l'essence, et qu'un véritable avantage au bénéfice des camions à gazogènes n'interviendra qu'à partir du moment où le prix du combustible de remplacement (provisoire ou définitif) sera aux environs de 0,40 du prix de l'essence. Ce rapport numérique permet de discuter la question au point de vue anglais.

RÉSUMÉ

The use of producer gas as fuel for heavy motor vehicles has to be studied from a technical as well as from an economic point of view. From the latter aspect, the possibility of utilisation depends on two factors—the resultant lower loading capacity and the price of fuel. A petrol engine, adapted for

gaseous fuel, will lose more than 30 per cent. of its horse-power efficiency. In order to compensate for this loss, there is a tendency to maintain the engine capacity by increasing the diameter of the cylinder. The development of suction gas vehicles using fuels of low ash content and of high reactivity, will tend in the direction of the reversed combustion type, without injection of steam, and purification of the gas by filtration through cloth. Although the design will necessarily differ from the petrol-driven type, the engine will be capable of rendering the same services. The load capacity, however, will be reduced in any case by 10 per cent. on account of the increased weight of the special equipment.

An ideal fuel should possess the following characteristics :—

High reactivity,
Low ash content,
High fusion point of the latter,
High mechanical resistance,

and in addition should be impervious to atmospheric humidity, and no tar should be formed.

In conclusion, it may be stated that suction gas producers for motor vehicles will be an economical proposition if suitable fuels can be obtained at a price of 40 per cent. of that of petrol.

ECONOMIC UTILISATION OF FUELS IN THE CZECHOSLOVAKIAN CERAMIC INDUSTRY

CZECHOSLOVAKIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

B. HELAN

Paper No. K3

CONTENTS

In the Czechoslovak Republic all work directed towards a complete and economical utilisation of fuel is centralised in the Institute for the Economical Utilisation of Fuel. The Institute has two departments: the heat-technological, occupied with the study of fuel as a source of energy, and the chemical department, occupied with the study of fuels as raw materials. The heat-technological department devotes itself to the study of heat economy in the various branches of industry, renders possible the application and use in practice of the results of its studies and works together with the special industrial organisations.

The Czechoslovak Republic is, after England, the richest country in ceramic raw materials and there is therefore in Czechoslovakia a well-developed ceramic industry, which, as is generally known, requires very considerable quantities of fuel for drying and burning. According to present experience, only a very small part of the fuel is utilised for the burning of ceramic goods even in the best of kilns, whereas the larger part represents losses. As our ceramic industry requires about 9·2 per cent. of the total quantity of brown coal hewn and about 3·4 per cent. of the bituminous coal hewn, or a considerable share of the total coal production, the Institute has made a special study of the heat economy of this industry and is

working together with the organisation occupied with the same subject, *i.e.*, the Heat-Technical Advisory Office of the Union of Porcelain Manufacturers in the Czechoslovak Republic and of the Union of Glass Manufacturers. In the porcelain, fireproof goods and lining brick industry, we know at least roughly the conditions prevailing in the burning of the goods and distribution of heat in the various types of kilns, and so the construction of the kiln and the guiding of the fire are adapted to make the kiln work as economically as possible. In the brickmaking industry, however, the question of heat economy has been neglected up to now. In the literature of this branch there are about three works dealing with the heat conditions and fuel consumption in circular kilns, and there is no mention of periodic kilns, but in the general manufacture of bricks and kindred goods it is necessary to ascertain the consumption of fuel and to find ways for its better utilisation. For this reason we have, first of all, made a systematic study of the utilisation of fuel in the brick-making industry. In Czechoslovakia about two milliards of bricks and about 200,000,000 of roofing tiles are produced annually, including a smaller quantity of special kinds of brick-makers' goods, and burning is carried on in about 3,600 kilns of Hoffmann type, zig-zag kilns of Geiger and Bührer types, and in many cases still in the ordinary field kilns. Roughly we may estimate that about two-thirds of the brick-makers' goods are burnt in circular kilns and the rest in glowing or periodic chamber kilns and partial circular kilns. According to our calculations the average consumption of coal for burning 1,000 bricks amounts to about 180 Kg. of coal of a heating value of 6,500 calories when burning in circular kilns and to 300 Kg. in glowing kilns, and the fuel consumed in the brick-making industry therefore represents about Kč 75,000,000.

We have paid the greatest attention to the study of the heat conditions in circular kilns in which it is possible best to utilise the heat, and also because the glowing kilns are being done away with and will be replaced by circular kilns, and we have therefore been able by exact measurement to ascertain exactly the balance sheet for heat of circular kilns of various types and dimensions and with varying daily advancement. The balance sheets for circular kilns published up till now have not been complete and have, therefore, not given us a correct picture of the utilisation of the heat.

Before starting systematic work we have therefore first of all drawn up a suitable method for arriving at the heat balance sheet,

which even during normal working would permit the distribution and utilisation of the heat to be ascertained.

We have established the heat balance sheets for about twenty-six circular kilns of all systems under varying working conditions, and have worked out proposals for the best operation and guidance of the fire and also for a suitable design of kiln.

If we consider carefully the principle of the circular kiln, we may say that if there were no losses of heat, no chemical reaction, and the fire itself moved forwards, no new heat would be required for burning the goods. In reality, however, alterations take place in the goods which require heat for the process, the fire cannot be advanced without the consumption of energy and, in addition, considerable external losses of heat occur in the working of circular kilns. If we continue our consideration, we may say that the fuel consumed in circular kilns serves only to counteract the heat of reaction and the heat losses, and therefore in the drawing up of heat balance sheets of circular kilns it would be necessary to ascertain within the limits of possibility these losses and the consumption of heat for chemical reaction. According to J. Matějka[1], the following alterations take place when burning brick-makers' goods. At about 110°C. the last hygroscopic water disappears from the goods, which was not entirely removed by the drying, and for the evaporation a certain quantity of heat is consumed. Above 500°C. the decomposition of silicon aluminate into its anhydride takes place at the expense of heat consumption and the freeing of a further quantity of water.

In the heat balance sheets of circular kilns it is necessary first of all to ascertain the heat required for the evaporation of the mechanical binding water and the heat required for the decomposition of kaolinite (*i.e.*, for the expulsion of the chemical binding water), in some cases for the decomposition of the carbonates of the alkaline earths and also the chimney losses (*i.e.*, the quantity of heat contained in the flue gases and the loss due to open chargers). The combustion air drawn in by the chimney does not suffice in many cases to completely cool the burnt goods, and it is therefore necessary to open the chargers above the burnt goods so that more air is drawn into the kiln. Of the further heat losses, the loss by imperfect burning must be mentioned, which in our experience is insignificant in circular kilns, and then the loss in heat of the balanced goods and the loss by radiation and in the channels. The

[1] Chemicke Listy, 1919, No. 8 a 9, Chemical Changes of Kaolinite by glowing.

fixing of the losses by radiation and in the channels has not yet been defined. and in our calculations we also have not ascertained these losses, In ordinary working we have ascertained the chimney losses, the heat required for the expulsion of the mechanical and chemical binding water, for the decomposition of carbonate of lime, heat losses escaping through the chargers or the heat for the drying plant and the heat in the balanced goods.

We shall now proceed to describe shortly our method of working in making up heat balance sheets. We fix the consumption of fuel as follows: when adding the first row of a new chamber to the fire, we measure its heat and commence to add weighed coal to the whole fire. During this experiment we regularly take samples of the coal being weighed, so that we can exactly ascertain in the laboratory the composition and heating value of the fuel burnt. We end the experiment when we have completed a given cycle. The distribution of heat over the whole fire and in that part being fired must be approximately the same. The coal left in the whole fire is weighed again, and we thus ascertain the quantity of fuel we have consumed in order to progress with the fire through a certain number of chambers or through a certain length of heating channel, and we assume that the coal consumed is equal to the fuel required by the goods charged in the respective part of the kiln for complete burning. For example, we start the test by adding the first row of the tenth chamber and finish by adding the first row of the fourteenth chamber and have consumed altogether eighty quintals of coal. The goods charged in chambers ten, eleven, twelve and thirteen have consumed for their complete burning under our assumptions eighty quintals of coal.

Some time ago we carried out this test and we have come to the conclusion that the fuel consumption only differs very slightly from chamber to chamber. The fuel consumption ascertained by this method has been calculated per 1,000 of products, further per 100 Kg. of burnt products and per cu. metre of kiln. The most important figure characterising the economy of the kiln is the fuel consumption per 100 Kg. of burnt product. The weight of the burnt product is ascertained from the average weights of the various kinds of goods and from their number. In our tests we have weighed ten pieces of each kind taken at random, weighed directly from the kiln. We have converted all calculations to the weight of the burnt goods in order to be able to compare the results. By comparison of the fuel consumptions per 100 Kg. of product and per cu. metre of kiln, it is possible to judge roughly how densely

the goods were placed in the kiln and the relation between the cubic contents of the inside of the kiln and the total outside radiating surface. For instance, with a very considerable fuel consumption per 100 Kg. of product should a normal or only very slightly higher consumption per cu. metre result, it is a sign that the kiln was charged relatively very thinly or that there are in the kiln side or cross walls which reduce the effective charging contents of the kiln. Further, if the fuel consumptions per 100 Kg. of product and per cu. metre of kiln both is very considerable, it is a sign of considerable heat losses, chiefly of losses by radiation and in the guide channels. It is, therefore, to be recommended that in addition to the fuel consumption, the so-called density of the charge be given, *i.e.*, the weight of goods per cu. metre of kiln.

The heating value of coal varies considerably, and therefore the results calculated for any one kind of coal could not be compared and we have therefore calculated the fuel consumption data for coal of a heating value of 6,500 calories. The quantity of heat required for the expulsion of all water, *i.e.*, mechanical and chemical binding, was calculated on the assumption that all water would be evaporated, even the chemical binding water, and that one Kg. of these waters in being heated from 0°C. to 100°C. and being changed into steam would consume 639 calories. This assumption is almost exactly correct even for the expulsion of the chemical binding water, liberated on the decomposition of the earthy matter. According to W. M. Cohn,[2], about ninety-four calories are consumed in the decomposition of kaolinite and the expulsion of chemical binding water per gramme of practically pure kaolinite. The heat of reaction is given at ninety-four plus/minus three calories. From the analysis of chemically pure kaolinite we know that it contains about 13·91 per cent. of water. If we assume that we have evaporated the chemical binding water at 100°C. we consume about eighty-nine calories or approximately that given by Cohn. As during burning some further weak exothermic reaction takes place, we hardly commit any mistake, if we calculate the heat required for the expulsion of all water according to our assumptions. The total percentage of water is calculated from the total losses by burning, which also include carbon dioxide from the decomposition of carbonates and the combustion of any minute quantities of organic matter.

If there is a considerable quantity of calcium carbonate present

[2] W. M. Cohn, Beitrag zur frage der Wärmewirtschaft in der Ker. Industrie. Berichte d. D. Ker. Ges. Bd. IV. s. 55.

in the clay, we calculate its weight in kilos and multiply by the heat of decomposition of calcium carbonate, *i.e.*, 415 calories, and so we calculate the quantity of heat required for the decomposition of the calcium carbonate present. We calculate the chimney losses from the quantity of burnt fuel, the composition and temperature of the flue gases. The composition of the flue gases is obtained by analysers of the Orsat or Deutz type. In order to be able to ascertain the quantity of air escaping through the open chargers and thus also causing losses in heat, we have measured at regular intervals the speed of the air flowing through the broken down doors with the chargers open to the kiln, and by a simple calculation we have ascertained the quantity by weight from the area of the doors and the duration of the test. From the analysis of the flue gases we calculate the quantity of air for burning, and the remainder is then due to the air escaping through the chargers. In order to find out the temperature of the hot air escaping, we place above one charger in each row of open chargers a mercury thermometer on a special type of tripod and at regular intervals of time we read off the temperature. We take the average of the figures measured and assume that the air escapes through all chargers at the same temperature. For measuring the speed of the air flowing to the kiln it is necessary to remark that with small advancements and chimney draught the speed with two to four doors broken down is normally so small that it must be increased artificially by measuring the speed at one door and during measurement closing all the others. This, however, admits some error, as we partially change the normal flow of the air; it is, nevertheless, not possible to ascertain the quantity of air reliably by other methods. If air is also drawn off from the burnt-out chambers for the drying plant, its quantity and temperature must also be found out, so that we can ascertain the quantity of heat led off to the drying plant. In this case, the air passing into the kiln through the doors serves for combustion, and is also led off to the drying plant, and finally escapes freely through the chargers above the kiln. The last of the losses which is to be ascertained, is the loss by heat in the balanced goods, which can be calculated very easily from the weight of the goods, their temperature and their specific heat. The other losses such as by radiation and in the guide channels, losses through the bottom of the kiln, could not be ascertained well at present, and we calculate them together with other small losses by difference. In the calculation of the heat necessary for the evaporation of the water, we have assumed that the water would be evaporated at 100°C.; if, now, the

chimney temperature is higher than 100°C., we must add to the chimney losses the heat carried away by the water vapour caused by the expulsion of the water contained in the goods, if its temperature is higher than 100°C. If, for instance, the temperature of the flue gases is 130°C., it is necessary to calculate what heat is necessary to heat the water vapour, which according to assumptions is caused at 100°C. to 130°C.

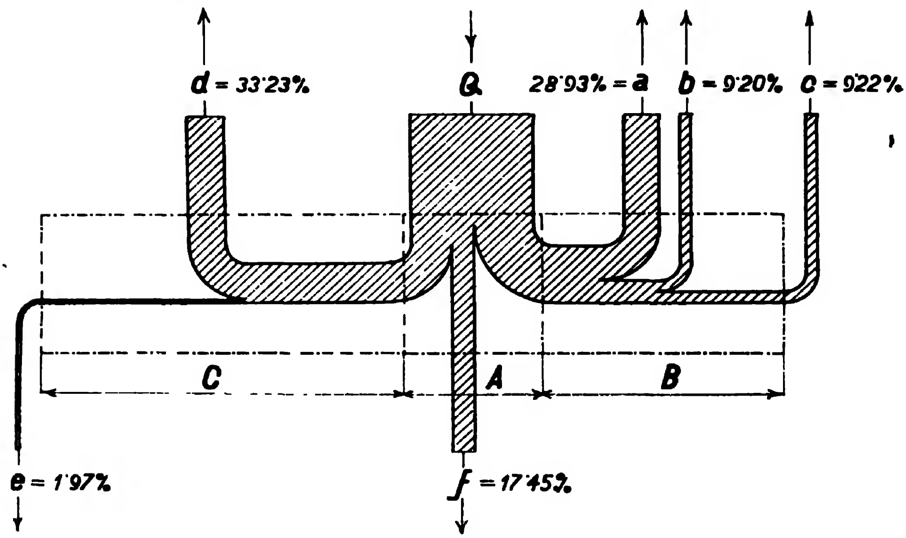

Fig. 1.

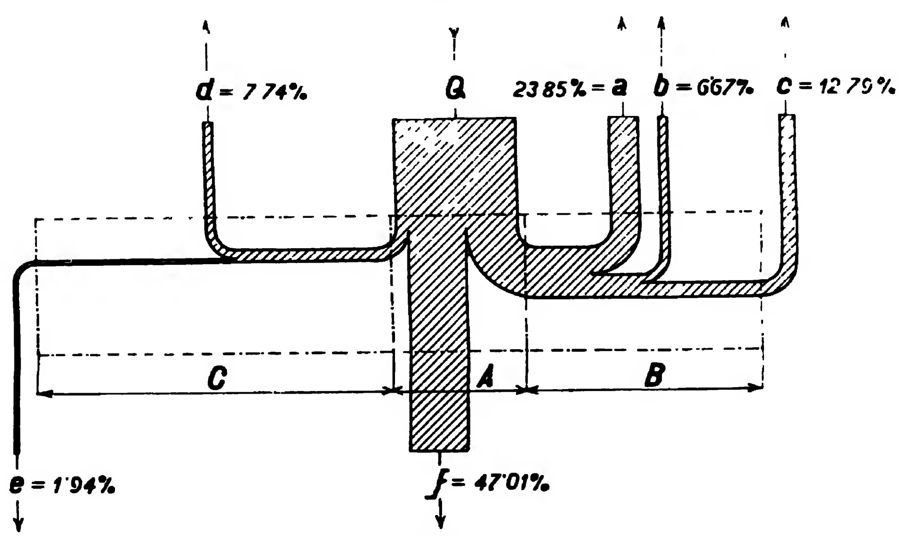

Fig. 2.

In diagram No. 1, the heat balance sheet of a circular kiln with chimney drive is given, made out according to the above methods,

Kiln No.	Type of Kiln	Length of heating channel in metres	Area of kiln section in metres sq.	Number of chambers.	Remarks.
1	Bock with top draught	126 8	12 39	16	
2	Bock chamber	108	11 43	12	eat partly used or drying
3	Hoffmann.	103 6	5 30	16	
4	Zig-zag "Geiger."	150	4 71	20	utomatic adding eat for drying
5	Hoffmann.	75	9 23	14	
6	Hoffmann	88	7 54	16	
7	Hoffmann	113	10 28	16	
8	Buhrer	214	6 71	26	at from burnt chambers used for rying
9	Buhrer	210	6 31	26	
10	Hoffmann.	85	9 06	16	
11	Kohout	103	9 48	16	eliminary drying,
12	Hoffmann.	96	9 16	18	ombined drying.
13	Kohout	75	7 34	12	raught on great ength before fire
14	Hoffmann	96	10 33	16	eliminary drying
15	Hoffmann	75	10 28	14	oal dust in bricks. including calorific value of coal dust
16	Hoffmann	65	6 08	16	Ditto
17	Hoffmann	65	5 73	16	Ditto
18	Hoffmann	81	6 15	16	reliminary drying.
19	Hoffmann.	109	7 52	18	Ditto
20	Kohout	70	7 03	14	
21	Hoffmann.	86	9 72	16	
22	Hoffmann.	63 5	6·68	14	ig-zag path of fire.
23	Hoffmann.	56·5	8·67	16	
24	Hoffmann.	72	8 19	14	Ditto
25	Hoffmann	100	7·60	18	
26	Hoffmann.	130	7 18	20	

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the kiln having a heating channel of 9·72 $m.^2$ section, and in diagram No. 2 for a circular kiln with a heating channel of 6·68 $m.^2$ with partition walls inside the kiln, which considerably reduce the effective cubic contents.

In the diagrams the following signs are used:—

- A part being burned.
- B part being heated.
- C part being cooled.
- Q total amount led to kiln = 100 per cent.
- a heat for evaporating water.
- b ,, decomposition of $CaCO_3$.
- c chimney losses.
- d losses through open chargers.
- e loss in heat of balanced goods.
- f unascertained losses.

In Table I., the results of the studies on circular kilns are given, together with the most important data of the working of the kilns. If we compare the various balance sheets, we find that the greatest influence on the economy of the kiln is exerted by the chimney losses, loss of heat escaping through the chargers and the unascertained losses, the most important of these being the losses by radiation, loss in guide channels and through the bottom of the kiln. The chimney losses in well-managed circular kilns vary between 10 and 15 per cent., the unascertained losses from 10 to 60 per cent. These losses arise in kilns with badly insulated bottoms, in kilns with heating channels of small section and with small advancement of the fire. The loss by heat escaping through the chargers never reaches 50 per cent., and is caused generally by small chimney draught, so that in order to attain a certain advancement of the fire, it is very soon necessary to open the charging openings to the fire. From the table it is evident that the circular kiln numbered 2 and 4 has the greatest fuel consumption. In the case of test No. 2, this is a circular chamber kiln with bottom transmission channel, in which the unascertained losses reach 60 per cent., and in which the fuel consumption is very high owing to these losses. Similarly in test No. 4, the unascertained losses are very considerable as the cubic contents of the kiln is not in this case efficiently utilised, as may be immediately judged from the density of the charge.

The smallest fuel consumption is shown by test No. 14. The kiln works with chimney drive, attains quick advancement and burns mostly thin-walled goods. The balance sheet of this kiln shows that the unascertained losses vary only round about 10 per cent.,

and also the other losses are relatively small, this explaining the low fuel consumption. The main reason, however, is the class of charge.

From the results of a series of trials we have drawn up instructions for the expert handling of kilns and hints for construction, which we can state shortly as follows:—

1. Complicated structures of circular kilns should be avoided.
2. Do not introduce preliminary drying plant.
3. Maintain a large length of goods in the fire.
4. Add very often in small lots or introduce automatic chargers.
5. Pay attention to quick advancement of the fire.
6. Pay attention to good insulation of the whole kiln, also to the bottom and its heat-proof quality.
7. Do not build kilns with short-heating channel; minimum length 60 metres for circular kilns, 100 to 120 metres for zig-zag kilns.
8. Pay greater attention to the chimney construction, and make the dimensions according to an expert's calculations.

The unascertained losses in well-insulated kilns with careful attendance and medium advancement of the fire amount to about 20 per cent. and the average fuel consumption of a heating value of 6,500 calories in circular kilns amounts to about 3·5 Kg. per 100 Kg. of burnt product.

In partial circular kilns according to the length of the kiln and the attendance about 4·5 Kg., in glowing kilns the average is 7·5 to 8·5 Kg. per 100 Kg. of burnt product.

In addition to the studies of the work on circular kilns, we have at the same time carried out a study of the heat conditions of various partial circular and periodic kilns, in order to obtain all necessary data for design and for judging the most economical kilns for a given annual production. In order that the results of our work can be used in practice as much as possible, we are collaborating with expert organisations of the ceramic industry.

RÉSUMÉ

En Tchécoslovaquie, tous les travaux dirigés vers l'utilisation plus complète et plus économique des combustibles sont centralisés dans l'Institut pour l'utilisation économique des combustibles. Après l'Angleterre, la Tchécoslovaquie est le pays le plus riche en matières premières céramiques. L'industrie céramique tchécoslovaque consomme 9,2 pour cent de la production totale de lignite et 3,4 pour cent de la production totale de houille. L'Institut pour l'utilisation économique des combustibles avec le concours de

la Société Céramique Tchécoslovaque a fait l'étude de la question de l'économie de chaleur dans l'industrie céramique, et ce sont ces travaux qui sont en partie exposés dans le présent mémoire.

Les études sur les fours circulaires sont très importantes, mais d'autres fours ont aussi été étudiés dans le but d'obtenir toutes les données nécessaires à la construction et au jugement de fours les plus économiques pour une certaine production annuelle spécifiée.

UTILISATION OF ELECTRICITY FOR INDUSTRIAL HEATING

CANADIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

A. T. STUART

Paper No. K4

CONTENTS

INTRODUCTION

Although the methods by which electricity is applied in industrial heating are many and varied, it is not a difficult matter for any interested person to inform himself concerning this subject by reference to books and current technical literature wherein such matter is already well covered. For instance, reference can be made to the concise survey of the subject in the series of articles on "Industrial Electric Heating," starting in the October 1927 issue of the *General Electric Review.*

With voluminous published information at hand, it would be of no particular interest or value again to review the present well-known practices of industrial electric heating. But, on the other hand, if it were possible to forecast some of the future developments in the use of electricity for such purposes, and to assist in some way to bring these developments to earlier fruition, something might be gained by dealing with the subject from such an angle in a brief paper of this kind.

In order to facilitate this it will be advisable to make some observations regarding both the present electrical and heating practices. By such an analysis it may be possible to name some of the essential principles and from them to synthesise new modes of practice which may be superior to the present ones.

ELECTRICAL ASPECTS.

In order to supply the rapidly growing demands for electricity, many thousands of millions of money have been invested for its development and distribution. Since the nature of the demand for electricity is largely governed by the habits of the customer population served, it is more usual than not to find that the total kWh. actually delivered and paid for represent less than half of the capacity of the generating stations, while the balance in capacity represents losses in distribution and undeveloped off-peak.

A study of some load curves of average American cities shows sharp daily and seasonal peaks in demand and deep valleys between. Often the records for a period of years indicate that these undesirable characteristics tend to become aggravated with the normal growth in load. As a consequence of such circumstances, the huge investments of capital could not show reasonable earning power if it were not for the fact that the cost of saleable power was sometimes doubled over what it would cost under continuous full load conditions.

The problem of supplying the demands for peak power, particularly for the seasonal peaks lasting but a few hours in the entire year, is a serious one. A common method of attacking it is to find means for reducing capital costs of plant necessary to take care of such peaks, even though there may result a sacrifice of energy efficiency. For such reasons it is often advisable to take care of increases in peak demand on water power plants by the operation of auxiliary steam plants, even though coal may be expensive and though more water power could be developed. This policy, of course, in no way eliminates peaks, but merely lessens their cost by shifting the burden to less expensive plants.

However, if we look at the problem the other way and if, instead of decapitating peaks, we could fill up the valleys in the load curves, it is obvious that there would be no peaks and no need for auxiliary steam plants when further water power is still available for development. Present electrical practice provides no universally applicable method for utilising off-peak, and consequently, it can be said that though the electrical industry has been successful in meeting the growing demands, it has not been successful in the converse—in fitting new demands to available supplies in off-peak on operating plants and in making full use of invested capital.

That power demands are not yet well cultivated is further indicated in the statistics showing the maximum capacity in water power of the world in relation to the capacity so far developed. For instance, in North America alone there still remain unutilised some 75,000,000 maximum horse-power, for some of which there is no immediate population to create a normal demand and some of which is in large excess of such demand. In addition to water power there are regions and circumstances (as when exhaust steam could be utilised) where steam power could be developed at costs comparable to water power if a waiting demand for electricity were at hand.

Since similar conditions exist throughout the world, and since it has been said that the total energy of all the electricity at present developed in the world does not equal 1 per cent. of the energy of the coal consumed annually, there is ample evidence of scope for research and development to find new means for utilising electricity.

At the present time the principal uses for electricity are in fields where fuels are substituted and seldom, if ever, is electricity used along with fuel in carrying out some industrial heating process. This observation then raises the question whether future developments may not be along lines whereby electricity and fuels may be used jointly and in such a way that greater overall efficiency may result than is now possible when each source of energy is utilised separately and in competition.

COMBUSTION

It has long been the general practice to burn raw coal in air, and in burning 1 ton of coal as much as 14 tons of air, containing 10 tons of inert nitrogen, are used. For purposes of high-temperature industrial heating there are, therefore, great limitations imposed by the use of "raw air," the 80 per cent. nitrogen of which greatly reduces flame temperatures. Since the flow of heat, like the flow of electricity, is governed by differences in potential, and since the flame temperature is reduced by nitrogen closer to the minimum temperatures required in industrial processes, often many times as much fuel must be consumed as should be theoretically required. Therefore, to some considerable extent, it is the presence of 80 per cent. nitrogen in air which has made it advisable to substitute fuels by electricity for some specific purposes.

The possibilities inherent in the use of pure oxygen, rather than air containing 80 per cent. nitrogen and only 20 per cent. oxygen, are well illustrated in the use of oxy-acetylene and oxy-hydrogen flames for the cutting of iron and steel. By means of pure oxygen temperatures comparable to those of the electric arc become readily available, and with the added advantages that the products of combustion are then available to distribute the head of the flame to the charge. There is no reason why the near future should not see low-cost oxygen made available for the enrichment of air for the combustion of fuels for all purposes of industrial heating. With this oxygen any fuel—such as pulverised coal, fuel oil, and natural and artificial gases—can be burned to produce either an oxidising, neutral, or reducing atmosphere in industrial furnaces, and with the control of the oxygen supply, even up to 100 per cent., it will be possible readily to attain higher temperatures and efficiencies. The supply of cheap oxygen to industry, therefore, will undoubtedly affect the future use of electricity for industrial heating.

Cheap oxygen will find use in many of the basic processes of industry, such as in the operation of blast furnaces, smelters, cupolas, ore-roasting equipment, metal melting and working furnaces and kilns for the manufacture of cement, glass, porcelain, abrasives, refractories, brick, tile, etc. Oxygen will also be used in operating all forms of equipment for processing fuels, such as for the carbonisation of coal and for its complete gasification, both in central gas works and in industrial plants.

By means of oxygen every kind of equipment for the gasification of all forms of carbonaceous fuel can be operated by continuous internal firing in such a way that there are no by-products or losses of fuel in the form of flue gases. Lump coal will probably be gasified in apparatus resembling a blast-furnace shaft from which ash can be discharged as slag. Other forms of fuel, such as coal, heavy oils, tars, lignites, peat, shales, etc., may be pulverised and sprayed into a nitrogen-free oxidising atmosphere, as has been suggested by Runge and Bourcoud. Apparatus for such purposes may perhaps resemble that of the McEwen-Runge process installed by the International Combustion Engineering Corporation, in one of the Milwaukee power plants.

These varied potential uses for oxygen have been the subject matter of considerable technical literature. With cheap oxygen, as is conceded by all authorities, will come low-cost domestic and

industrial gases as well as means for the production of low-cost high-temperature heat in metallurgical and ceramic industry. Both low-cost fuel gas and low-cost oxygen for combustion will be bound to react on all present markets for electricity in domestic, industrial, and municipal fields. If the source of this oxygen is to be air, little power will be required, but if much of this oxygen is to be generated from water, the consumption of electricity will be great, and consequently, instead of being a competitor, oxygen may be the means for vastly extending the use of electricity into the industrial heating load.

However, if the problem of industrial heat were solely an oxygen problem, as it has usually been treated by writers, there would be little prospect of water being the future source of oxygen. But the problem is also one of fuel, and we are not limited to the use of raw fuels as supplied in nature. Hydrogen, as generated from water by electrolysis along with oxygen, is itself a valuable fuel, which even now suppplies half of the heat of artificial gases.

FUEL

There is reason to believe that future fuels will be largely fluid and that the need for solid fuel will greatly decrease. With regard to the need for solid domestic fuels, few will question the great advantages which will come with the delivery of cheap gas; and, with regard to the need for solid fuels in industry, reference may be made to Vol. 51 (1927) of the Proceedings of the American Electrochemical Society and to Bulletin 270 (1927) of the U.S. Bureau of Mines, to show that many authorities agree that gases will replace coke for the reduction of ores. For tangible evidence of such conclusions we see the project to supply gas from the Ruhr over the whole of Germany in competition with coal, and also the erection of a plant by the U.S. Steel Corporation to reduce 250 tons of iron per day by gases and without coke.

The fluid fuels, which may supplant solid fuels entirely, are especially rich in hydrogen, and their constituents include free hydrogen gas, carbon monoxide gas, various hydro-carbons, and alcohols, made up from the elements carbon, hydrogen, and oxygen. Although coal contains only about one part of hydrogen to fifteen parts of carbon, the hydrogen content of these fluid fuels (also having regard to the proportions in which they will be in demand) will average about four parts of hydrogen to fifteen

parts of carbon. Accordingly, to convert 1 ton of coal into fluid fuel will require 300 lb. of hydrogen, and the production of this hydrogen will demand the decomposition of 1.35 tons of water.

In the present practice of city gas works and of the various industries using vast amounts of free hydrogen (such as nitrogen, coal liquefaction, and other industries), steam is decomposed by hot coke and a mixture of free hydrogen and carbon-monoxide is generated. When hydrogen alone is required, the carbon-monoxide is decomposed by steam and a mixture of hydrogen and carbon-dioxide results, which latter is separated from the hydrogen. These methods of making hydrogen require large amounts of coal, and even in regions of low-cost fuel the costs of hydrogen ready for use is said to be about 75 cents per 1,000 cu. ft.

As previously concluded, the fluid fuels of the future will be composed of liquid and gaseous hydrocarbons, free hydrogen gas and carbon-monoxide. It is obvious that there will be a definite ratio in demand for these constituents, and it is obvious that there will be a definite limitation to the relative amount of carbon-monoxide gas which can be used. This amount will be governed both by the relative demand for liquid fuels and by the fact that too much carbon monoxide content in gases is not desirable on account of its poisonous effects.

It has been shown that in treating 1 ton of coal it will be necessary to decompose 1.35 tons of water in order to obtain the hydrogen necessary to compose fluid fuels. But this water contains about 1.2 tons of oxygen—an amount vastly in excess of what could appear as carbon-monoxide, even if great amounts of coke were used to handle it. The point is that, in order to make fluid fuels in proper proportions to meet future demands, it would be essential to use perhaps 80 per cent. of surplus carbon-monoxide to produce hydrogen by the steam reaction above described. This would mean high-cost hydrogen, and consequently high-cost fluid fuels.

It is interesting to note that future fuels will require a greater tonnage of water than of coal in their preparation, and that of the energy developed from the utilisation of these coal products perhaps half will come, not from coal, but from the hydrogen originating in the water consumed. It is obvious, therefore, that the fuel problem of the future concerns, chiefly, not how to gasify coal, but the best means for decomposing water in order to obtain

hydrogen. The limitations of the present practices for making hydrogen from water have been discussed, so it is pertinent to discuss now the process of decomposing water by electricity.

Electrolysis of Water

In decomposing water by electricity there is theoretically no loss of energy, and the energy of the electricity consumed can be recovered by the combustion of the hydrogen gas. If this gas is burned in air, the oxygen produced is saved and represents a gain in material.

In practice, apparatus for the electrolysis of water can be operated at close to 90 per cent. efficiency and produce 60,000 cu. ft. of hydrogen and 30,000 of oxygen per horse-power year, so that power imposes a cost of 1.1 cents per 1,000 cu. ft. of both gases for each $1 cost in power. All costs, other than power, need not exceed 5 cents per 1,000 cu. ft. With this basis, water power companies could utilise their own off-peak capacity in the generation of hydrogen and oxygen at about 5 cents per 1,000 cu. ft., or they may utilise prime 24-hour power at costs of about 25 cents per 1,000 cu. ft. Similarly, off-peak on steam plants could be used at the cost of extra fuel only and produce the gases at also about 25 cents. When ideally located with regard to both cheap coal and cooling water, even 24-hour steam power might be developed and used to generate the gases at comparable costs.

Electrolytic apparatus can be made entirely automatic and at a low first cost. There is no reason why its operation should not be conducted at costs as low as those of electric steam generators, which are now installed in Canada to a total capacity of 750,000 H.P. While there is no great difference in efficiency and there may be no great difference in first cost of equipment, the electrolytic products are many times as valuable as steam. Electric steam generators have but limited use, and the product is only sufficiently valuable to return about $7 per horse-power year consumed. Yet it has been claimed that this invention has made possible the immediate development of the Gatineau and Saguenay Rivers in Canada—a statement which emphasises the potential importance of electrolytic cells.

As compared with the electric boiling of water, the electrical decomposition of water produces products universally applicable in the basic processes of industry. The present prices at which hydrogen and oxygen are sold in cylinders is equivalent to as

much as $1,800 per horse-power year, but even if we take the low prices of from 25 cents to $1 per 1,000 cu. ft. of hydrogen, and from 50 cents to $1 per 1,000 cu. ft. of oxygen, the equivalent for power is from $30 to $90 per horse-power year as compared with $7 per horse-power year for steam.

Electrolytic Gases

Electrolytic hydrogen would be available directly for use. Perhaps the poorest use, but one always available to absorb surplus hydrogen, would be to use it as a fuel gas in industry or to mix it with other artificial gases in gas works or in industrial gas plants.

Hydrogen also is capable of use as a substitute for metallurgical coke for the reduction of ores. It is, perhaps, the ideal reducing agent in that it picks up sulphur and phosphorus from ores, and in that surplus hydrogen coming from ore-reducing equipment can be easily purified and recirculated for its complete utilisation. In view of what has previously been said about the future possibilities of the reduction of "steel direct from ores" by gases, hydrogen assumes enormous potential importance.

As a material for the syntheses of important products, hydrogen is of the greatest importance. In the fixation of nitrogen alone the world consumption of pure hydrogen reaches an annual total of perhaps 100,000,000,000 cu. ft. This consumption will doubtless be exceeded in the Bergius process, by which hydrogen is forced directly into combination with coal, lignites, tars, heavy oils, etc., in order to produce light hydrocarbon oils and gases. Again, in the processes of Fischer, Partart, Audibert, Du Ponts, and others, hydrogen can be combined with carbon-monoxide gas to produce various alcohols for fuels and other purposes. Other uses for hydrogen include the manufacture of soaps and edible fats from animal and vegetable oils; the cutting, welding, brazing, annealing, and melting of metals; the inflation of dirigibles; the burning out of oxygen from air to make nitrogen; the manufacture of synthetic rubber; in the dye industry; for encasing electrical generators (as developed by the General Electric Co.), etc., etc.

The vast potential uses for oxygen in the gasification of fuels and in enriching air for combustion, as previously commented upon, will provide low-cost heating gases for all consumers and, what is of the utmost importance, high-temperature heat at low

cost for the metallurgical and ceramic industries. It is only the electrolytic process for decomposing water which will make it possible to keep hydrogen and oxygen separate, so that oxygen can be used as, when, and where desired. Thus, by the use of electricity and coal we have the basic and essential elements. carbon, hydrogen, and oxygen, separate, so that they can be combined in any desired proportions to produce any desired composition of fluid fuels, and so that surplus oxygen is kept separate from such processes for air enrichment in the combustion of all forms of fuel.

Although to the casual observer hydrogen and oxygen may appear to be rare and unimportant gases, the fact is that they, along with carbon, are the most essential and basic materials of life and industry. Probably one-half the heat of all fuels on the average originates with the hydrogen content and half with carbon, and all heat is liberated by combustion in oxygen. By weight the annual hydrogen tonnage of the world is a considerable fraction of all fuel tonnage and the annual oxygen tonnage is perhaps five times the weight of all fuels burned. Perhaps the only reason why hydrogen and oxygen are not more familiar terms is that, in spite of all our modern invention and refinement, we still use two of the most essential materials of industry in the crude or natural forms.

Through the agency of the process for the electrolysis of water it will be possible for electricity to invade fields now monopolised by coal and other fuels, in part substituting fuels entirely and in part co-operating with fuels to perfection in their use. Thereby electricity can be applied to the winning of values from natural resources in coal and in metallic and non-metallic minerals. Such new and universal uses for electricity are, therefore, not restricted to populated regions, and in the future it may be an anomaly to find undeveloped water power and unutilised deposits of minerals lying side by side as they do to-day. It is not unlikely that these new methods for the "Utilisation of Electricity for Industrial Heating" may change the whole domestic and industrial heating situation as we know it to-day.

ZUSAMMENFASSUNG

Die zur elektrischen Heizung gegenwärtig angewandten Methoden und Apparate sind gut bekannt und in der technischen Literatur zur Genüge erörtert worden; es kann daher im vorliegenden Bericht auf gewisse

Seiten und Probleme eingegangen werden, die über die zu erwartende Praxis der Zukunft Aufschlüsse geben.

Die wichtigen Bestandteile der in industriellen Heizvorgängen verwendeten Brennstoffe und Luft sind Kohlenstoff, Wasserstoff und Sauerstoff. Der in Naturbrennstoffen enthaltene Kohlenstoff und Wasserstoff tragen an die Versorgung der Welt mit Wärmeenergie etwa zu gleichen Teilen bei, obwohl jeder den andern ersetzen könnte. Sauerstoff ist zur Wärmeerzeugung aus Brennstoffen unbedingt erforderlich; der jährliche Verbrauch an Sauerstoff beläuft sich dem Gewicht nach etwa auf das Fünffache des gesamten Brennstoffverbrauchs. Wasserstoff und Sauerstoff sind für das Leben und für die Industrie unentbehrlich. Zur Zeit werden sie erst in der rohen Form von Brennstoff und Luft verwendet; sie in reiner Form billig herzustellen wird eine Revolution auf allen lebenswichtigen Gebieten der Welt nach sich ziehen.

Die Erzeugung von Wasserstoff und Sauerstoff aus Wasser mittels Elektrizität erschliesst somit ein ungeheures Tätigkeitsfeld für die Verwendung der Elektrizität zur industriellen Heizung und wird zur Vervollkommnung der Verwertungsweise der natürlichen Mineralien- und Energie-Quellen führen.

THE FUEL QUESTION IN THE CEMENT INDUSTRY

DANISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

O. V. MORCH

Paper No. K5

CONTENTS

Many books have been written about the manufacture of Portland cement, and weekly journals in many countries deal with details regarding the manufacture, the qualities and the prices of the product. The following is an attempt to describe the fuel question in connection with the cement industry, by indicating, firstly, the ways in which fuel is used in the manufacturing process; secondly, the standpoint of the industry to-day as regards fuel economy, with special regard to the efficiency of the methods employed, and, lastly the magnitude of the question.

SECTION I—CEMENT MANUFACTURE AND METHODS OF FUEL UTILISATION

The cement industry as we know it to-day is of very modern origin. A patent for the manufacture of Portland cement was first taken out by the Englishman Aspdin in 1824, but Portland cement as now used was manufactured only to an inconsiderable extent before 1844. All through the nineteenth century the output of Portland cement

increased steadily, and by the end of the century the yearly output was enormously augmented.

Portland cement is manufactured in nearly every country in the world and the following table gives approximately the present production.

OUTPUT OF PORTLAND CEMENT IN 1926

In Europe	about	22,700,000	metric tons
In America		30,000,000	,,
In Asia		4,800,000	,,
In Africa		600,000	,,
In Australia and New Zealand		900,000	,,
Total	about	59,000,000	metric tons

MANUFACTURE OF PORTLAND CEMENT

Limestone, clay or shale and a suitable fuel are the principal raw materials for cement making. About 1·6 to 1·75 tons of raw materials are required to produce 1 ton (metric) of cement.

The industry can only reach any considerable magnitude where limestone, clay or shale can be acquired cheaply and where the works can be placed conveniently for transport of the resultant product.

An equally important factor, however, is that of the fuel. The cost of fuel for cement making is often *more than half of the prime cost of the cement*, and it is, therefore, no wonder that the right application of fuel has been given special attention by both cement manufacturers and the designers of cement works.

Fuel is used at a cement works in two ways—directly, for burning the cement, and, indirectly, for the generation of power for driving the various machinery.

When it can be stated that many kilns to-day use 0·4 tons of coal for burning one ton of cement, whereas others use only 0·2 tons, and that in some cases absolutely modern works use 140 kWh. per metric ton of cement, whereas other modern works produce equally good cement with 75 kWh. per metric ton, it will be understood that there are great variations in practice, due mainly to variations in raw materials, furnaces, and plant.

To give a clear picture of the whole problem, therefore, requires a description of the various processes employed by the cement manufacturers to-day.

PROCESSES

Portland cement is made in only one way. The raw materials are crushed and ground to a very fine state of division and then burned into clinker. The clinker is again ground into powder, this being the cement. The plant consists of crushing and grinding plant, burning plant, and various transporting apparatus, with additional plant for packing the cement into bags and barrels. Most of the fuel is utilised for the processes first mentioned.

In accordance with the way the raw materials are treated cement manufacturers speak about a *wet* process or a *dry* process. *The wet process* denotes that the raw materials are ground with the addition of water. It is used when it is required to treat chalk and clay which can be washed in wash mills into a paste (slurry); and it was originally used for these materials only. It is, however, now used for the treatment of hard raw materials, which, after being crushed in large crushers are ground with water in large tubular mills using balls and flint pebbles or balls and "cylpebs" (cylindrical metallic grinding bodies) as grinding media.

At some places 6 kWh. suffice for the total grinding of soft materials for 1 metric ton of cement, whereas at other places the crushing and grinding of the corresponding quantity of hard raw materials takes as much as 55 kWh.

The wet process has the great advantage that variations in the composition of the raw mixture can easily be made before it enters the kilns, as at this point the raw materials are mixed with water. By means of currents of air or mechanical agitation other slurry can be mixed with that first made. Another advantage of the wet process is its cleanliness and the absence or partial absence of dust from the kilns. Further, wet grinding generally requires less power than dry grinding.

The disadvantage of the wet process is the somewhat higher fuel consumption in the kilns. The slurry mentioned contains about 35 to 45 per cent. water, which must be evaporated. This requires the employment of a certain amount of heat, but it will be seen later that there is rarely any necessity to incur any cost for fuel directly for this purpoes, and in any case the expenditure is partly counterbalanced by the less amount of fuel used for power in the grinding process.

In the *dry process* the raw material is ground, dry, into a powder. Disadvantages of this process are experienced in the difficulty of mixing the powdered raw material; the loss of dust from the powder in the kiln, and the large amount of power used in grinding.

This process has an advantage in the less amount of fuel generally used for burning the material. An important offset to this is found in the fact that the raw material must, as a rule, be dried in driers thereby incurring more dust losses, before it can be pulverised.

CRUSHING AND GRINDING PLANT

It is not the place here to describe such plant in detail, but a few facts are of special interest when dealing with the fuel requirements of the cement industry.

First of all modern quarry practice is tending in the direction of larger and larger units. It was, and still is, the practice in many quarries to work by hand or with small drills. However, it is becoming more and more common even for small cement works to employ rock drills and mechanical navvies (steam or electrically driven), which with their shovels pick up pieces several feet in diameter. Mechanical navvies strong enough to handle such pieces, and crushers large enough to crush them, naturally are of very large dimensions, and the hourly output of such plant is no longer dependent on the hourly output of the works. Consequently, whereas it is most economical to run the rest of the factory day and night, a few hours' work a day of the electrically driven navvy and the larger crushers is enough. Such conditions give a peak load during the time when the crushing plant is at work, unless special arrangements are made. That this peak load is of importance will be seen from the fact that an ordinary large size shovel and crushing plant takes about 500 to 600 H.P. to drive, and one of the largest crushers alone as much as 500 H.P.

Types of Grinding Mills used

For grinding the raw material numerous types have been used. For the wet process mostly ball and tube mills, for the dry process ball and tube mills, but also a large number of high-speed grinders, utilising as grinding media single balls or cylinders which are driven round at high speed, the material being ground between them and an outside cylinder.

Most raw mills are designed to run practically day and night, and an even amount of power has to be provided throughout that time.

For the grinding of clinker (with a small addition of gypsum) ball and tube mills or high speed mills are used, as for the grinding of raw materials, and these mills also run day and night.

The following will give some idea of the sizes of the grinding plants in use at present. Old units rarely take more than 100 H.P. to

drive, whereas up-to-date larger mills often are driven by 600 to 700 H.P. motors. The largest mills made take 1,200 H.P. when running and over 2,000 H.P. for starting.

The mills used for grinding the coal do not differ materially from mills used for supplying pulverised fuel for boiler plants. It is a necessity that coal mills for rotary kiln plants should be of a most reliable design. Often a factory has only one kiln and one coal mill, and the latter must run twenty-four hours a day. The kiln in many cases does not stop producing cement clinker for six months or more or at least it does not stop for more than an hour or two per week during that time. Accordingly, cement works managers have shown a preference for the more slow running, reliable type of coal mills, even if they sometimes use more power per ton of coal ground.

For many years the central coal grinding station held the field, and coal dust was stored for an odd hour or for use on Sundays, but in late years airswept mills, which deliver straight into the kilns, have also found favour with cement works manufacturers when coal with only small contents of moisture is available.

DRYING PLANT

The limestone and clay or shale used in the manufacture of Portland cement generally contains moisture. When these materials are used in a wet process plant this moisture is of no consequence, but when the dry process is used it is imperative that all the moisture be dried out, otherwise the raw "meal" cannot be ground to the extreme degree of fineness desired.

For drying the raw materials drying towers have been used, but during later years the rotary drier has entirely taken their place. Various designs are in use, but the efficiency is never very large. The gases passing through the drier may originate either from an ordinary brick furnace, a combustion chamber around a coal dust flame, or from the rotary kilns. In the latter case the drier uses the waste gases from the kiln. Driers rarely show an evaporation greater than 3 to 4 kg. of steam to 1 kg. of coal (standard coal of 7,000 calories gross). For drying the coal similar driers are used.

For the manufacture of 1,000 kg. of cement generally 2,000 kg. of raw materials and coal are required. If the average amount of moisture is taken as 8 per cent., 175 kg. of water have to be evaporated. Consequently, about 50 kg. of coal are used in the drying plants per metric ton of cement produced.

KILNS FOR CEMENT BURNING

It is necessary to go a little more into the details of the kilns. It is not a question of kilns for the dry process and the wet process only, but there are two entirely different types of kilns, the stationary kiln and the rotating kiln.

The stationary kiln was the type first employed for cement making. It is still in use, but important alterations have been made since its invention.

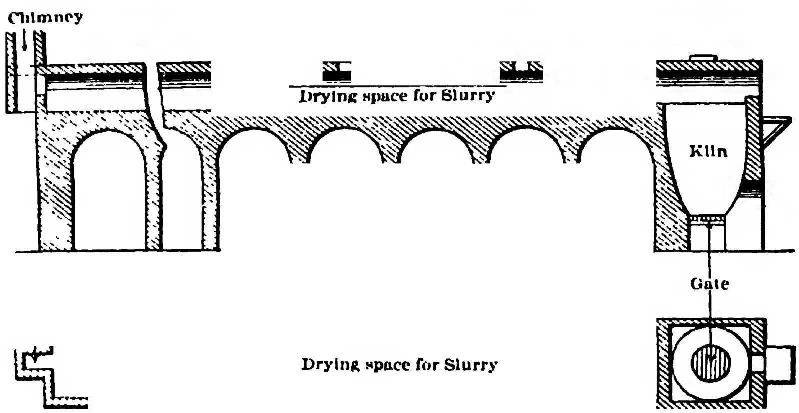

Fig. 1. Section through a Johnson kiln (chamber kiln with drying floors for slurry).

The Stationary Discontinuous Kiln

Fig. 1 shows a section of a chamber kiln used in England for the wet process. The slurry was run out upon the drying floors, and when dry was wheeled into the kiln where the dry lumps were stacked together with the fuel, which consisted of coke. The whole was lighted by means of faggots and the kiln burned itself out. As the burning progressed the limestone was calcined and finally fused with the clay into a clinker.

Kilns similar to the one illustrated in Fig. 1 are in use to-day and produce a good Portland cement, but the quality is not as regular as that produced in kilns of a more modern type. The output of the first kilns of this kind was from 5 to 8 tons a day, the consumption of fuel as much as 40 to 50 per cent. of the weight of the clinker produced.

The Stationary Continuous Working Kiln

Fig. 2 illustrates a Dietsch shaft kiln. This is mostly used for the dry process. The materials are dried, ground, and pressed into

briquettes (with a small addition of water). The briquettes are thrown into the kiln together with the fuel. Such a kiln has an output of 10 to 20 tons per day, with a fuel consumption of 15 to 20 per cent.

Fig. 3 shows another type of stationary continuous kiln, the *Aalborg kiln.* Through the special openings part of the fuel is thrown into the kiln. The output is from 10 to 15 tons per day, and the fuel consumption from 15 to 20 per cent.

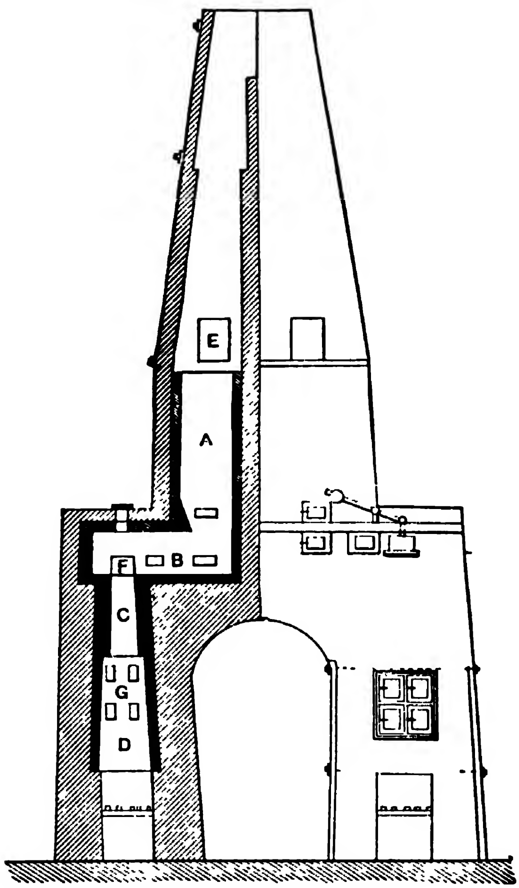

Fig. 2. Dietsch shaft kiln.

The advantages of the stationary kiln lie in the very small radiation losses (on account of the thick brickwork) and the efficient utilisation of the heat. The exit gas temperature is very low. It is a disadvantage that the material tends to stick to the sides of the kiln and that settlement of the charge takes place during the burning.

It is questionable whether the cement from stationary kilns can

comply with the continually increasing demands for an improved quality of cement. The fuel consumption is, however, low and for this reason these kilns, in their modern form, enjoy a certain amount of popularity, especially where ordinary shaft kilns have been used.

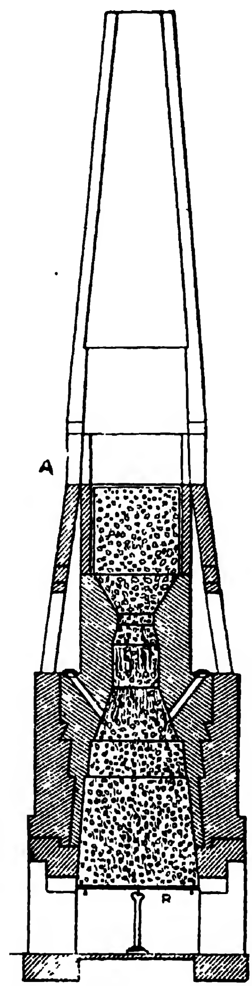

Fig. 3. Section through an Aalborg kiln.

An offset against the lower cost of fuel is the extra labour involved in preparing the charge, and these kilns suffer from the disadvantage of all dry kilns; they give off a large amount of dust, especially if forced draught is used.

Rotary Kilns

These were introduced about the year 1897. The first one was made in England somewhat earlier, but rotary kilns did not come into commercial use till coal dust firing was applied in America. The first kilns used in Europe were of American design and had an output of about 40 to 50 tons per day. The largest kilns made to-day are for an output of about 400 tons per twenty-four hours.

A distinction must here be made between rotary kilns for the dry process and for the wet process.

Rotary Kilns for Dry Process

The first rotary kilns made were only some 16 m. (50 ft.) long.[1] They were very inefficient, the amount of fuel used being as much as 35 to 40 per cent. of the weight of the clinker produced. There

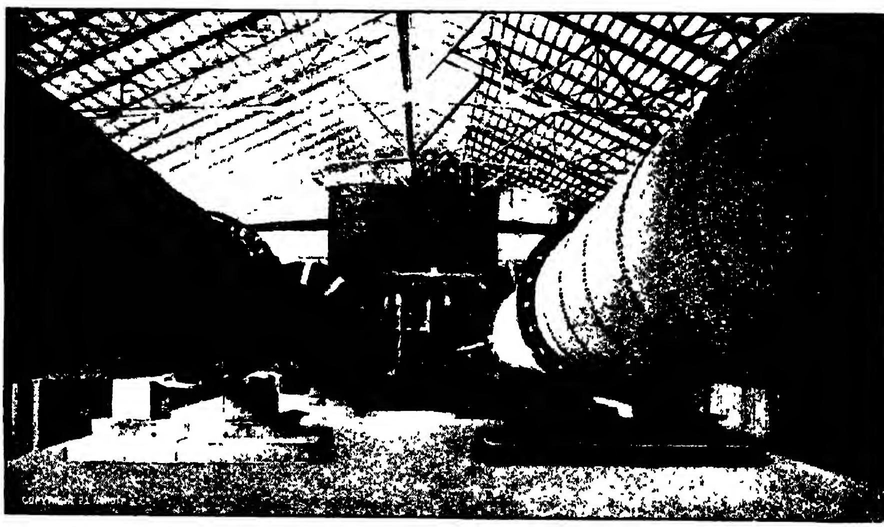

Fig. 4 Two modern large kilns fitted with coolers of the recuperative type. The burning zone is of enlarged diameter.

are still a large number of kilns working not more than 20 to 30 m. (70 ft. to 100 ft.) in length and consuming a good deal too much coal. What may be termed an ordinary dry process kiln to-day is a kiln of about 2·7 m. (9 ft.) diameter, 45 m. (150 ft.) length, and with an output of 150 tons per twenty-four hours.

The material is fed into the top end as a finely ground powder. The gases carry about 5 to 15 per cent. of this powder out of the kiln and out through the chimney if dust catchers are not installed.

While the kiln rotates, the rest of the material travels slowly down the kiln, is calcined, and at the end of the kiln clinkers under the influence of high temperature. At the outlet the clinker drops

out into a cooler, in which it is cooled by the passage of a current of air. The heated air is discharged through a chimney, fresh cold air being used for the combustion of the coal, which is blown into the kiln through the burner pipe

The temperature of the outlet gases is about 800° to 1,000°C. (1,472° to 1,832°F.) and of the clinker leaving the kiln, 1,000°C. (1,832°F.); consequently the losses at both ends of the kiln are very heavy. Still there are scores and scores of such installations working to-day.

Rotary Kilns for Wet Process Plants

There is a greater variety of rotary kiln plants in use for wet process than for dry process. The wet process rotary kiln plant was first developed in Europe and to save coal, which generally speaking formed a larger proportion of the cost of production in Europe than in America, proper coolers allowing part of the clinker heat to be regained have been in general use in most wet process plants for the last twenty years. Only a relatively small amount of the clinker heat was, however, regained in most of the coolers.

SECTION II—EFFICIENCY OF FUEL UTILISATION

Efficiency of Ordinary Rotary Kilns for Dry Process

The processes of calcining and clinkering are so complex that figures for the heat necessary for these processes given by various authorities show very large variations. Tests with numerous kilns have, however, enabled engineers to calculate heat balances with sufficient accuracy to give satisfactory results in most cases. The efficiencies mentioned later for various types of kilns are based on such tests and heat balances.

A calculation can be made of the amount of heat theoretically required for

(1) drying what moisture there is in the raw meal fed into the kiln,
(2) for calcining the lime (eliminating the CO_2)
(3) for burning the clinker,

on the basis that (a) the clinker leaves the plant at the same temperature at which the raw material is supplied; (b) the gases leave at the temperature of the surrounding air; and (c) no radiation losses are allowed for.

If calculated as the ratio between this theoretical figure and the fuel actually consumed, the efficiency of an ordinary dry kiln plant

as mentioned above, with a fairly modern kiln, but with no regeneration of the clinker heat, is only about 22 per cent.

Efficiency of Improved Rotary Kiln Plants with Waste Heat Boilers

It is therefore natural that improvements have been made, but it is remarkable that they have not yet come into more general use.

At the outlet end of the kiln a cooler has been placed *directly under the kiln* and a fairly airtight connection made between kiln and cooler. The air for burning the clinker is drawn through the cooler into the kiln with the result that the clinker heat is not entirely lost.

During most recent years coolers have been placed *at the end of the kilns* (recuperative coolers), making the loss of clinker heat still smaller.

As regards the losses at the inlet end, the following improvements have been made. Electrical dust precipitation plants have been introduced, saving up to 93 to 94 per cent. of the dust formerly lost. (In many places the authorities have threatened to stop dry process plants if such dust installations were not provided.)

Further—and here comes the greatest improvement in the rotary kiln for dry process—waste heat boilers have come into use. As said above, the temperature of the gases leaving a dry rotary kiln is often 800° to 1,000°C. (1,472° to 1,832°F.). After passing through suitable boilers and economisers the temperature of the gases leaving the plant may be decreased to 180°C. (356°F.), and, in many cases, enough steam is produced in such boilers to run the whole factory.

The heat consumption per kilogramme of clinker in a modern dry process kiln plant with proper clinker cooler and waste heat boiler installation is thus enormously reduced. The efficiency of such a plant can be calculated in two ways. It can be calculated in the way mentioned above for the efficiency of ordinary dry rotary kilns. If so calculated the efficiency of some of the most modern kiln plants with waste heat boilers attached is *about 67 per cent.*

The cement works manager who operates a modern plant with waste heat boilers is, however, apt to calculate the efficiency of his kiln plant in the following way. In any case he must have steam to run his power plant, and as the best coal-dust fired modern boiler plants have an efficiency of, say, 82 per cent., he is entitled to say, "I produce clinker and steam for A per cent. of coal, the steam produced is equal to B per cent. of coal used in a modern boiler plant, consequently I use only A—B per cent. of coal for

my kilns. Theoretically I should only use C, and the efficiency is thus $\frac{C}{A-B}$."

Calculated in that way the efficiency of a modern dry process plant is *as much as 75 per cent.* By comparison with the efficiency of the ordinary dry process plant mentioned above (22 per cent.) it will be seen that the improvement made is very large indeed.

The disadvantages of the dry process generally have been mentioned in the above. A drawback which to some extent minimises the economical value of the waste heat boiler is that the plant has to be specially arranged in order to equalise the load over twenty-four hours of the day. It was especially mentioned on a preceding page how a peak load of eight hours or less originates in the quarrying and crushing plant, and this must be counterbalanced somehow by using other parts of the plant only sixteen hours a day. This means, however, larger units of mills, larger motors for driving these, etc. It is also a drawback that such plant must run without cessation on Sundays, as otherwise too much valuable steam is wasted. In rare cases special arrangements can be made with neighbouring power stations to absorb the surplus power from the cement works.

A waste heat boiler is a very expensive item, as the heating surfaces must be large on account of the relatively low temperature of the gases. Further, an auxiliary boiler or an auxiliary furnace for the waste heat boiler is necessary in order to supply steam while the kilns are stopped.

Efficiency of Ordinary Rotary Kilns for Wet Process

A kiln which was quite modern only five years ago, with a diameter of 2·4 m. (8 ft.) and a length of 50 m. (165 ft.), a fairly good cooler and ordinary chimney draught and about 36 per cent. of water in the slurry, had an efficiency of about 48 per cent. Most rotary kilns for the wet process are still of this class.

The exit gas temperature of such a kiln is about 550°C., and there is, therefore, room for improvement.

Efficiency of Improved Rotary Kilns for Wet Process

In the more modern rotary kiln plants for wet process a waste heat boiler is often added and the cooler is attached to the end of the kiln (recuperative type). In such a plant about 80 per cent. of the steam necessary for the running of the works may be obtained. The efficiency is *as much as 68 per cent.* If the value of the steam

is put equal to that from the best modern boiler and allowance made accordingly as in the case of the rotary kiln for the dry process, the efficiency is *as much as 72 per cent.*

The first cost of such plant, like the first cost of a dry process kiln plant with waste heat boiler, is high, but an economical wet process rotary kiln can also be arranged in a different way. In quite recent years the working of the rotary kilns has been more closely studied, and by making special arrangements in the dryer end of the kiln it has been possible to get the temperature of the exit gases down to about 200°C. (392°F.). For such kilns an efficiency *as high as 67 per cent.* has been obtained without waste heat boilers.

Combustion in Rotary Kilns

If boiler plants of low efficiency are examined it is often found that the firing is at fault, generally through using a large excess of air. This is not the case with rotary kiln plants. As a rule not even the plants with a very low efficiency will show high contents of oxygen in the gases. In most rotary kiln plants ordinary good attendance makes it possible to burn with an excess of air of only 5 to 10 per cent. The amount of air is regulated by means of the chimney damper, and the kiln and its lining is suitable to withstand the high temperature obtained by working with a small excess of air. As a matter of fact a high temperature, 1,450° to 1,550°C. (2,640° to 2'820°F.) is necessary in the sintering zone of the kiln.

Wet versus Dry Process

It is not difficult to imagine from what has been written above that there are strong advocates both of the dry process and of the wet process. This has been of great value to the cement industry. The advocates of the one process will naturally try to improve their particular type of plant to compete with plants of the other system. It is also natural that there are some who prefer wet process kilns with waste heat boilers, and others who prefer economical wet kilns working with a similar efficiency but without waste heat boilers.

It is extremely difficult to compare results from one plant with results from another, since raw materials, fuel, etc., vary, and consequently one man obtains the best results with one kind of plant and another with the competing type. It is, however, very often the local conditions which decide the type of plant. Scarcity of water, for instance, determines the adoption of dry process plants.

In other cases there is no question of waste heat boilers, because the management, in order to save capital, decides in the first instance

to buy all the power from a power station. In such cases the wet process with the economical kiln has no rival.

Fuel for Stationary Kilns

For mixing with the material in a kiln such as the Aalborg kiln, a coal low in volatiles, coke or anthracite is usually employed. For adding to the material while burning a fuel somewhat higher in volatiles is used.

Fuel for Rotary Kilns

A great variety of fuel has been used for this purpose.

Bituminous coal with 25 to 35 per cent. volatile matter has given the best results (judged by output) of the kilns, but it is always the question of what can be purchased at the cheapest price. Rotary kilns can also be worked with coal containing as little as 15 per cent. volatile matter and it is possible to mix anthracite with bituminous coal, this being common practice.

Coal with 25 per cent. ash has given good results. If the content of ash is much in excess of that, difficulties often arise. A considerable amount of ash sticks to the clinker and raw material in the kilns, and the remainder goes up the chimney. The ash which remains in the kiln has no proper chance to mix with the raw material, and tends therefore to lower the quality of the cement. As a consequence (other things being equal), a coal not too high in ash is preferable.

Brown coal and *lignite* of low calorific value but with high content of volatile matter have been used in many cement works. In Germany, Austria, Poland, and Czechoslovakia such fuel has been in common use for years. Drying of such fuel, which gives off gases at a very low temperature, is difficult. It is possible to use in cement-making the residues from carbonisation of inferior coals, either alone or mixed with other fuel, and with the development of the low temperature carbonisation many cement works hitherto dependent on expensive fuel may possibly look forward to obtaining a suitable fairly cheap fuel.

Peat is also a cement works fuel. In some countries like Denmark large quantities were used for burning of Portland cement during the war. It was air dried and then ground and mixed with 33 per cent. coal.

Oil has been in common use for rotary kilns in America, in factories on the Black Sea, in Siam, etc. Special oil burners are used.

Producer gas has been tried. Ordinary producer gas, however, is of so low calorific value that very special arrangements (for instance

additional coal dust firing) must be made to get the high temperature required for clinkering the material in the kiln. It has therefore never come into general use.

Natural gas has frequently been used in America and in Roumania. The composition of the gas at the latter place is about 99 per cent. CH_4, 0·2 per cent. N_2, and the calorific value about 7,750 calories per cubic metre at 15°C. and atmospheric pressure.

Waste Heat Boilers

It is a curious thing that rotary kilns should be in use for so many years before waste heat boiler plants were added to the equipment. In the original Portland cement plant in the Nazareth district (Pennsylvania) Dr. Irving A. Bachman conceived the idea of

Fig. 5. Rotary kiln with waste heat boiler in Australia (water tube boiler).

generating steam from the heat in the kiln gases, but a boiler installed was a failure, as it was found impossible to keep the boiler clean. In 1903 another attempt was made, and it was so far successful as to generate one-half of the steam required to operate the entire plant.

A waste heat boiler is, however, very expensive, and better results were necessary to establish the waste heat boiler as a commercial success. Such results were not forthcoming till about 1915, and as late as at the end of 1922 only about thirty waste heat boiler plants were in operation.

The reason why satisfactory results were so slow in being attained

may to some extent be the crudeness of many rotary kiln installations, especially those for the dry process. The smoke chamber at the top end of the kiln was generally built in brickwork, which cracked and opened in many joints. Further, there was no tightening device between kiln and smoke chamber. Consequently air leaked in, and the temperature registered in the smoke chamber was considerably reduced.

For the wet kiln this infiltration of air was so serious that it entirely nullified the possible savings in heat consumption. For years engineers accepted that the temperature at the inlet end of the wet kiln was 300° to 350°C., but when measured properly it is, for an ordinary kiln, more than 500°C., which makes all the difference.

Types of Boilers Used

Generally speaking, it is the water tube boiler which has found most favour, although in a few plants the fire tube boiler has been installed. Boilers of the Babcock type have been extensively used, but boilers with vertical tubes have been preferred by others. Waste heat boilers must be specially designed to suit each separate case according to volume and temperature of gases. The suitable design of the superheater is a part which must be watched, especially where the temperature of the gases is low and at the same time a high degree of superheat of the steam is desired.

Generally speaking, waste heat boilers for rotary cement kilns are more easily operated than ordinary boilers because of the low temperature of the gases, but they must be properly designed, and special attention must be paid to the devices for cleaning the boilers from dust.

FUEL USED FOR POWER

As said in the beginning of this paper the consumption of power at a cement works varies from 75 to 140 kWh. per metric ton of cement, but although the design of mills has been enormously improved of late years there is often no decrease in the amount of power used, as greater fineness of the product is required. Cement is often ground to a fineness corresponding to a residue of only 1 per cent. on the 180 mesh sieve, and such grinding requires a very large amount of power.

On the other hand, for the auxiliaries, for transport, packing, etc., pneumatic machinery is becoming the accepted practice. It is much simpler and more reliable than mechanical transport, but

again it requires more power. The tendency is to substitute machines for manual labour, especially that of the rougher kind, and thus the consumption of power must naturally increase.

SECTION III—STATISTICS OF FUEL USED AND POSSIBLE SAVINGS

The Amount of Fuel used in the Portland Cement Industry

There are no statistics dealing with this question, and the following is, therefore, only an estimate of the amount of fuel used in the industry to-day.

In the table given below all fuel is reckoned as standard coal of 7,000 calories (12,600 B.Th.U. gross). It is further assumed that 120 kWh. are required for power purposes per metric ton of Portland cement made by the dry process and 110 kWh. per ton of cement made by the wet process.

TABLE SHOWING THE AMOUNT OF FUEL USED AT PORTLAND CEMENT WORKS WITH ROTARY KILNS (*Dry Process*).

Kilograms of standard coal (7,000 cals. per kg.) per 1,000 kg. cement.

	Ordinary rotary kiln plant (average of kilns made during the last twenty years and still in use)	Modern rotary kiln plant with waste heat boilers.	Average plant in 1926 (reckoning that about 15 per cent. of the total is modern).	Possible savings to-day.
	kg.	kg	kg.	kg.
Coal used in rotary kilns ..	270	250	—	—
Coal used for generation of 120 kWh electricity ..	110		—	—
Coal used for boilers during irregular runs of the rotary kiln plant ...	—	10	—	—
Coal used for drying raw material and coal (average 8 per cent moisture) ...	50	45		
Total coal used (kilograms per 1,000 kg. cement) ...	430	305	412	107

TABLE SHOWING THE AMOUNT OF FUEL USED AT PORTLAND CEMENT WORKS, WITH ROTARY KILNS (*Wet Process*).

Kilograms of standard coal (7,000 cals. per kg.) per 1,000 kg. cement.

	Ordinary rotary kiln plant (average of kilns made during the last 20 years and still in use).	Modern rotary kiln plant with waste heat boilers	Modern rotary kiln plant with economical kiln and modern power plant.	Average plant in 1926 (reckoning that 15 per cent. of the total is modern).	Possible savings to-day.
	kg	kg	kg.	kg.	kg.
Coal used in rotary kilns	320	310	240	—	—
Coal used for generation of 110 kWh electricity ..	100		90	—	—
Coal used for 20 per cent. of 110 kWh = 22 kWh. ...	—	20	—	—	—
Coal used for drying coal (average 8 per cent moisture) .	7	7	5	—	—
Total coal used (kilograms per 1,000 kg cement)	427	337	335	413	78

TOTAL CONSUMPTION OF FUEL IN THE PORTLAND CEMENT INDUSTRY IN 1926

Tons (1,000 kg.) of coal of 7,000 cals. per kg. gross.

	Total annual output. (Tons-1,000 kg.)	Per cent of total output.	Average amount of fuel used per ton kg.	Total amount of fuel used. (Tons-1,000 kg.)
Plants with dry process rotary kilns	30,500,000	51·8	412	12,550,000
Plants with stationary kilns reckoned as dry process rotary kilns but allowing 5 per cent. less fuel	4,500,000	7·6	391	1,760,000
Plants with wet process rotary kilns	24,000,000	40·6	413	9,910,000
Total, in 1926 ...	59,000,000	—	—	24,220,000

Part of the power used in the Portland cement industry is generated at water power stations, and this source is becoming of greater and greater importance. In countries like Canada most of the power used at cement works is generated in this way. As no information is available as regards the amount of water power used, this question is left out of consideration.

Conclusion

It will be seen from the preceding tables that the question of fuel in the Portland cement industry is one of considerable importance. Great efforts are being made in order to obtain economical working, and although the efficiencies of the most modern rotary kiln plants are not quite as good as those obtained in the most modern coal dust fired boiler plants, the difference is not very large.

The foregoing tables will show that with modern kilns and modern power plants it is not impossible yet to save fuel corresponding to 85 kg. of coal per ton of cement produced or, say, 5,000,000 metric tons per annum.

On the other hand, side by side with the request for economy in fuel goes the request to improve the quality of the product. It has been shown that somewhat less fuel is consumed in the dry process plant, whether with stationary kilns or with rotary kilns, but in spite of that the development is absolutely in favour of the wet process plant. In the same way the request for a better product compels the Portland cement manufacturer to spend more power for grinding, with a consequent increase in consumption of fuel.

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In writing the foregoing paper the author has had the collaboration of various of the experts of F. L. Smidth & Co. A/S., and his paper is based on the general knowledge and wide experience of this company.

RÉSUMÉ

La production mondiale en ciment en 1926 est évaluée à 59.000.000 de tonnes.

Dans la fabrication du ciment Portland le combustible joue un rôle très important, puisqu'il entre souvent pour la moitié dans les frais d'exploitation.

Le combustible consommé par cette industrie sert en partie au séchage et à la cuisson des matières premières, en partie au développement de force motrice.

La quantité de combustible nécessaire et la consommation de force sont soumises à des variations extrêmement fortes suivant les matières premières et les méthodes employées. On distingue le procédé à sec, suivant lequel la matière est séchée avant d'être cuite, et le procédé à humide, suivant lequel la matière est broyée à humide, après quoi la pâte est séchée et cuite au four.

Le procédé à sec exige en moyenne pour le séchage des matières premières et du charbon environ 50 kg de charbon par 1.000 kg de ciment.

Quant aux fours à ciment, on distingue le four stationnaire et le four rotatif. Les premiers sont discontinus ou continus et ont surtout été employés autrefois. Les exigences toujours croissantes quant à la qualité du ciment rendent la lutte contre la concurrence difficile aux usines qui se servent de ce type de fours. Pendant ces dernières années on a employé un four à cuve modifié avec grille tournante et travaillant avec de l'air sous pression.

Le four rotatif, chauffé au charbon pulvérisé, fut introduit vers l'an 1900. Il existe une quantité de vieux fours courts de ce système, aménagés pour le procédé à sec. Ces fours sont fort peu économiques et ont été remplacés ces derniers temps par de plus grands fours travaillant conjointement avec des chaudières récupératrices.

Il existe également un grand nombre de petits fours rotatifs, peu économiques, travaillant suivant le procédé à humide. Pendant ces dernières années on a commencé à les remplacer par des fours rotatifs travaillant conjointement avec des chaudières récupératrices, ou par des fours de construction spéciale dont l'effet utile est très élevé, grâce aux dispositifs spéciaux y installés en vue de rendre aussi efficace que possible le séchage de la pâte et d'utiliser la chaleur des scories.

Avec les fours à sec en combinaison avec des chaudières récupératrices on a obtenu un effet utile de jusqu'à 67 pour cent, pour les fours à humide avec des chaudières récupératrices, environ 68 pour cent, et avec les fours extra-économiques environ 67 pour cent, tandis que l'effet utile des fours anciens n'est que de 22 à 48 pour cent.

Comme combustible pour les fours stationnaires on emploie du charbon et du coke, pour les fours rotatifs du charbon, du lignite, de la tourbe, de l'huile et du gaz naturel.

Les moulins à charbon pour les cimenteries ont pour la plupart été disposés en centrales.

Quant aux chaudières récupératrices on s'est servi de beaucoup de types différents; cependant les chaudières à tubes d'eau soit du système Babcock et Wilcox, soit du type à tubes verticaux sont les plus courantes.

La consommation de force motrice par tonne de ciment s'élève à 75—135 kW-heures.

Dans des tableaux, il a été indiqué comment on peut évaluer la consommation de charbon par tonne de ciment, et suivant le procédé à sec, et suivant le procédé à humide. Pour les installations actuelles travaillant suivant le procédé à sec, cette consommation est évaluée à environ 412 kg et pour le procédé à humide, à environ 413 kg en moyenne. En conséquence, la consommation mondiale en combustible des usines à ciment Portland est évaluée à 24.220.000 tonnes.

Si toutes les anciennes installations étaient remplacées par des installations modernes, on compte qu'il y aurait une économie d'environ 5.000.000 de tonnes de combustible par an. Or, les exigences toujours croissantes posées à la qualité du ciment ont pour effet une augmentation de la force motrice nécessaire pour le broyage du ciment. Il est donc probable que la consommation en combustible d'une usine à ciment moderne augmentera à l'avenir.

WOOD PRODUCER GAS FOR THE TREATMENT OF SILVER ORES

DUTCH EAST INDIAN NATIONAL COMMITTEE

A. VAN HOEK

Paper No. K6

CONTENTS

Introduction

The silver ore occurring at Tambang Sawah on the island of Sumatra (Dutch East Indies) belongs to the so-called refractory type, as only a very small amount of the precious metal can be extracted by direct treatment with cyanide. Practically all the paying ore comes from the zone of oxidation and contains a considerable percentage of manganese dioxide, which acts as a retainer of the silver. The mining engineer, M. H. Caron, in collaboration with the Bureau of Mines at New York, experimented with the ore and worked out a method which is now in practice at Tambang Sawah. The experiments showed that most of the silver is present in a combination with manganese dioxide which is insoluble in cyanide. If this manganese silver compound is heated in a reducing atmosphere the manganese dioxide is reduced to manganous oxide and the silver is liberated in the form of minute particles of metal, which are easily dissolved by cyanide. To prevent re-oxidation it is necessary to ensure that no oxygen can come in contact with the ore while it is cooling. The heating as well as the reducing and cooling is done by means of gas derived from wood, in rotating furnaces which will be described later.

The Fuel

Though several seams of coal are known and mined in Sumatra the costs of freight are so heavy as to make the use of coal for the

generation of gas at Tambang Sawah prohibitive. The mine is surrounded on all sides by tropical forest, therefore wood is present in abundance and is the most suitable material for the gas producers.

The forest is built up of all kinds of trees and, as everything is cut down, the resulting fuel consists of a mixture of greatly varying components; hard, tough and heavy pieces alternating with light, juicy and more porous ones.

The material as cut down cannot be directly used owing to its high moisture content of over 50 per cent. which is at most times augmented during transport by the heavy rainfall, which ranks amongst the highest in the world. To get rid of the excess moisture, the wood, in pieces 4 ft. in length, is piled up in open sheds where the percentage is brought back to about 35 in three months' time. A longer stay would bring this number even further down but this would involve the building of many more sheds at great cost. As the moisture of the average fuel may not exceed 30 per cent. it is necessary to mix the wood from the sheds with dryer material. This is procured in two ways. Part of the fresh wood is heated in primitive ovens of earth round a wooden framework and fired by wood; these ovens have a capacity of about 30 cubic metres and it takes ten days to make the wood sufficiently dry for use. Another part is dried in a mechanical oven by the flue gases from the reduction kilns. The flue gases are forced by a fan through a channel of reinforced concrete where an endless belt is moving at very low speed. In this way 15 to 20 cubic metres are dried per day, depending on the original moisture contents.

All cutting and splicing of the fresh fuel is done by hand, each labourer getting a fixed daily task. Where possible the transport is done by rail, but often when the country is too hilly and irregular, steel cables and trolleys are used with advantage. On the principal road electric traction is available for the distribution to the various drying sheds. In addition to the wood a small quantity of charcoal is used in the generators; this is manufactured in ovens of simple design.

The Gas Producers

Tar and other by-products being valueless in the process, the producers used are of the down draft type. As will be seen from the diagram given (Fig. 1) a vapourising ring is provided round the ash zone, the supply of moisture-bearing air to the space above the fuel being controllable by means of a valve. From the pressure side of the fan which draws the gas from the producer through the

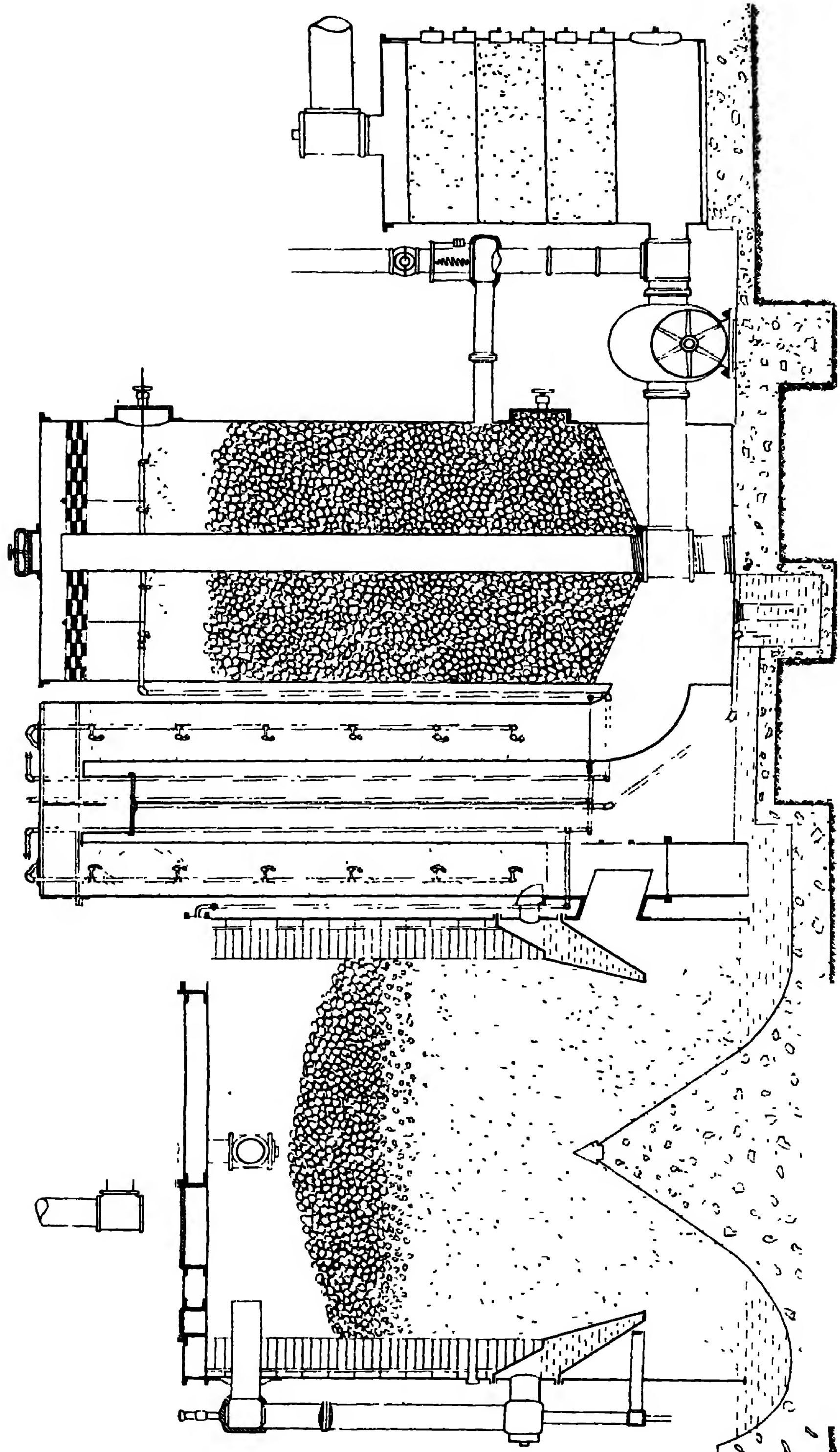

Fig. 1.

cooler and scrubber a by-pass is provided in order to allow for the re-circulation of surplus gas through the scrubber.

The second gas producer is provided with a shaking grate as difficulties were encountered with the ash-bed. These difficulties have now been overcome, and the shaking grate is the more troublesome to handle as after a few months' service it tends to become clogged and loose at the joints.

THE GENERATION OF THE GAS

As a rule the difference in pressure is 4 to 5 in. water gauge between top and bottom of ash-bed. The surplus ash is drawn off out of the waterseal; once a shift being usually sufficient to keep the pressure gauge normal. Unburnt charcoal which is drawn off with the ashes is collected and after air drying used again. Above the ash-bed comes the zone of incandescence, the zone of generation of the gases. Here the heat-liberating reaction of the burning of the coal and the heat-absorbing reactions for the forming of carbon monoxide and hydrogen must be kept in balance. Moreover the complicated hydrocarbons are cracked into stable gases. To make it possible for all these reactions to take place the thickness of the firebed must be at least 2 ft. but preferably more (up to 4 ft.) to compensate for possible holes, which easily form with the coarse fuel. On the top of the fire zone follows the zone where the wood is distillated, forming the gaseous products which are drawn through the fire zone and charcoal.

The topmost layer consists of the newly charged green fuel which is in the act of drying. This top layer must be kept dark. No flames should be visible; any clear place that shows itself should be covered with new wood or charcoal.

The stoking is regulated by means of a calorimeter which records the heating value of the gas in B.Th.U. per cubic foot. This meter is constantly watched and as soon as it drops under the normal value a signal is given whereon the stokers open the doors and add new fuel, level it out and darken the bright places. This has to happen as quickly as possible for the opening of the doors gives an excess of air that is not desired. Great care must be taken that no channels form in the fuel bed through which the draft may concentrate and cause big holes to burn in the firebed further down. The wood is charged in logs of 1½ ft. by about 6 in.; in the beginning longer pieces were thrown in but difficulties were encountered due to the fact that the long pieces caught into each other, leaving cavities and in consequence an irregular distribution of the suction.

A drawback is the lack of uniformity of the fuel. As stated before there are dozens of kinds of trees in the forest all differing from each other. One catches fire easily and is quickly consumed, another takes a long time. In the first place a hole may readily form, in the second the firebed may diminish. It takes, therefore, a rather fine discrimination on the part of the man in charge of the plant to blend his fuel in such a way that neither can happen.

The moisture of the wood is daily analysed from the sawdust.

The amount of vapour admitted through the vaporiser over the fuel bed can be regulated by a valve ; in practice this regulation is often done by leaving the feeding doors slightly ajar, thereby getting some air directly from outside.

Poking through the top holes is done thrice a day at the same time as the removal of the ashes. In order to be able to penetrate with the irons to the bottom it is necessary to have the green fuel bed shallow at these times. Clinkers are formed only in small amount and do not interfere with operation. In the beginning thick crusts of this material were baked on the cone, the sides and through the ash-bed, probably in consequence of a deeper firebed with occasional holes, causing a higher temperature in the ash-bed and partial fusion of the ashes. Charcoal is added to cover up bright places in the upper zone and in a general way to enrich the gas.

The plant is in charge of a European overseer, with Chinese shift bosses for the three shifts ; the labourers are natives, for the most part imported from Java. It takes eight men per shift to run the two units.

The normal production for both is 90,000 cu. ft. per hour with a heating value of 115 B.Th.U. This is kept constant by means of the calorimeter, but the percentages of the components are not always the same, due to the varying moisture and composition of the wood and to the condition in the producer itself. The principal constituents are :—

CO_2 14 – 19%
CO 6 – 10%
O_2 0·2 – 1%
H_2 16 – 24%
CH_4 2 – 4%
N_2 50 – 55%

The average fuel consumption per day is 60 cubic metres (piled) and 6 cubic metres of charcoal, approximately a dry weight of respectively 22,500 and 2,000 Kg. About 55 per cent. of the calorific value of the fuel is recovered as gas. From the given

description it will be seen that a great deal depends on the human factor. A permanent control by the calorimeter and a prompt action on its indications are essential. It is absolutely impossible to fill up the generator and leave it alone without detrimentally affecting the generation of good gas ; only by careful watching and a regular arranging of the fuel bed every few minutes may good results be obtained. This necessitates the use of several workmen, but as labour is still relatively cheap in this country this factor is not so important here as it might be in other parts of the world where the wages are higher.

General Data

Inside diameter of generator	10 ft.
Fuel burned per hour	2200 lbs.
Fuel gasified per sq. ft. of fire area per hour	28 lbs.
Gas generated per lb. of fuel	40 cu. ft.
Caloric value per lb. of fuel	8,460 B.Th.U.
Water consumption per hour	8,500 Br. Imp. gallons.
Temperature of gas under grate... ...	375°C.
,, ,, water vaporiser ...	95°C.
,, ,, ,, cooler	60°C.
,, ,, ,, scrubber ...	50°C.
,, ,, gas leaving plant ...	25–30°C.
Pressure of gas leaving plant	20–22 in. water gauge.
Percentage of ash	3½%
,, of coal in ash	16%
Power for driving exhauster	10 H.P.
Speed of exhauster	210 R.P.M.

Costs

The total expenses for cutting, drying, sawing and transporting the wood to the gas factory amounted in 1927 to 104,400 guilders.

For charcoal	13,200 guilders
For labour and supplies	21,200 ,,
Total	138,800 ,,

During the same period 21,000,000 cubic metres of gas were generated. Thus the costs were 0·66 cents (0·132 pence English currency) per cubic metre of gas generated.

The Use of the Gas

The furnaces in which the ore is reduced and heated are rotating kilns. The gas enters through a 6-in. pipe into a box at the lower end, which is fitted to the kiln with an airtight joint permitting its rotation. The bottom of this box opens into a pit filled with

cyanide solution ; through the box at the centre of the kiln runs the air pipe, which passes through the cooling zone, then bends outward through the shell of the kiln and once outside follows the length of it: in this part at distances of 4 ft. branch off nine smaller pipes, which pierce the shell again and end in the centre of the kiln with an elbow. The smaller pipes are each fitted with a cock, to regulate the amount of air to be admitted at the burners. We get, thus, a cylinder filled with combustible gas which can only be ignited at the places where the air pipes enter. The ore rolls by the rotation of the kiln and its slight elevation slowly through the zone of combustion. Here it is heated to the required temperature and is at the same time reduced by the surplus of the reducing gases. After having gone through this stage it enters the cooling zone, where a completely reducing atmosphere reigns ; here it cools, thereby preheating the entering gas and the air which passes through the pipe. At the end of the cooling zone it drops into the solution at the bottom of the box from which it is drawn by drag conveyors, for further treatment.

The temperature is controlled by base metal thermo-couples, which register automatically on a recorder. By regulating the inflow of the ore the temperature is kept as steadily as possible at 730°–760° Centigrade. In order to minimise heat losses by radiation the kiln has a double lining, soft insulating bricks next to the shell and then common firebrick.

ZUSAMMENFASSUNG

Die Silbererze von Tambang Sawah (Sumatra) sind wegen ihres Braunsteingehaltes nicht ohne weiteres zu verarbeiten ; zur Erzeugung einer guten Extraktion ist es nötwendig, das Erz über 700° C zu reduzieren und dann wieder abzukühlen ohne Zutritt von Luft. Dies wird erreicht durch den Gebrauch von Gas, das aus Holz generiert wird (Caron-Verfahren). Das Holz wird gewonnen im Urwald, der sich ringsum ausdehnt und die verschiedensten Holzarten aufliefert. Das frische Holz ist zum direkten Gebrauch zu feucht und muss erst getrocknet werden. Teilweise geschieht dies an der Luft in offenen Schuppen, doch wird hierdurch die Feuchtigkeit nicht genügend heruntergebracht, sodass spezielle Trockenöfen und auch die Abgase der Reduzieröfen dazu verwendet werden. Der Brennstoff wird in Stücken von 45 cm an die Gasfabrik abgeliefert. Weil möglichst aller Brennstoff in Gas umgesetzt werden soll, ist der Gasgenerator vom Saugegas-Typus. Hierbei werden Teer und schwere Kohlenwasserstoffe durch ein Bett glühender Kohlen gezogen und in stabile Gase zerlegt. Das Gas wird gekühlt und gereinigt und schliesslich in die Leitung gepresst zum Gebrauch in den Öfen. Zwei Generatoren sind aufgestellt, die pro Stunde rund 2 500 m³ Gas von 1 035 Cal produzieren. Wasserstoff, Kohlenoxydül und kleinere

Mengen Methan sind die nützlichen Hauptbestandteile. Die Arbeit wird kontrolliert durch ein Calorimeter, das den Heizwert des Gases notiert. Hauptsache ist, für eine gute Feuerschicht im Generator zu sorgen, da hier die Region ist, in der sich die Reaktionen abspielen. Löcher dürfen sich nicht bilden, da hierdurch ein unregelmässiger Zug entsteht; auch soll der obere Teil des Brennstoffbettes dunkel gehalten werden. Die Verschiedenheit der Holzsorten und auch ihre Feuchtigkeit machen die Arbeit schwierig, und standige Aufsicht ist absolut nötig. Auf das Signal des Calorimeterwarters, dass der Heizwert sinkt, was alle paar Minuten vorkommt, muss sofort neuer Brennstoff auf helle Stellen aufgeworfen und das Holz im Generator geradegezogen werden.

Das Gas wird in rotierenden zylindrischen Öfen gebraucht, um die Erze zu reduzieren und zu erhitzen, während auch die Kühlung in diesem Gase stattfindet. Die Öfen stehen unter geringem Böschungswinkel zur Horizontalen, wodurch beim Umdrehen das Erz sich langsam von oben nach unten bewegt. Unten kommt das Gas in den Ofen, weiter oben an der Zylinderwand sind die Luftrohre angebracht; nur hier kann Verbrennung stattfinden, während der Überschuss an Gas die Reduktion besorgt. Auf seiner weiteren Fahrt nach unten passiert das Erz das unvermischte kalte Gas, wobei es kuhlt ohne Luftzutritt.

DIE GASWIRTSCHAFT AUF DEUTSCHEN HÜTTENWERKEN

(THE USE OF GAS IN GERMAN IRON AND STEEL WORKS)

VEREIN DEUTSCHER EISENHÜTTENLEUTE

DR. BANSEN

Paper No. K7

CONTENTS

Die deutschen Hüttenwerke sahen sich am Ausgange des Krieges vor der Aufgabe, mit einer unzulänglichen Brennstoffbelieferung eine grösstmögliche Stahlerzeugung zu schaffen. Die Bestrebungen, das Gichtgas bestens auszunutzen, führten von den Grenzfragen der Wärmeerzeugung und -übertragung tief in die Wechselwirkungen mit den metallurgischen und betrieblichen Fragen hinein. Dadurch ist die Wärmewirtschaft zum Schrittmacher der allgemeinen betriebswirtschaftlichen Arbeitsweise geworden. Diese rechnet zwar nicht mehr nach Wärmeeinheiten, sondern nach t und Mark. Sie pflegt aber grade deshalb die Bewirtschaftung des Brennstoffes weiter, weil er 20 bis 30% der ganzen Selbstkosten des Walzeisens bedeutet, der Wert des Gichtgases $\frac{1}{6}$ bis $\frac{1}{7}$ der Roheisenselbstkosten beträgt, und nur die zielbewusste Erfassung und Behandlung des Gases die Aufrechterhaltung der gesteigerten Leistung sichert. Die straffe Organisation der Querverbindung aller Betriebe durch das Gas ist die erste Bedingung für die störungs- und reibungsfreie Abwicklung des fliessenden Fertigungsganges eines modernen Hüttenwerkes.

A. DAS GICHTGAS

I. *Die Erzeugung.*—Die Aufgabe des Hochofens ist die Trennung des Erzes von seiner Gangart und die Bindung des Erzsauerstoffes. Dieser beträgt mit geringen Schwankungen bei dem Gehalt von 20 bis 30 % FeO der meisten Erzmöller 280 m³ Sauerstoff/t Roheisen aus Erz. Er kann 1. durch Kohlenoxyd gebunden werden. Ist dieses aus irgend einer Quelle vorhanden (Formengas) und herrscht bereits Reaktionstemperatur (durch die Abhitze der Gestellreaktionen), so ist weder Kohlenstoff noch Wärme zusätzlich erforderlich (indirekte Reduktion).

Der Erzsauerstoff kann ferner auch 2. durch Kohlenstoff unter Bildung von Kohlenoxyd gebunden werden. Für die beiden Oxydationsstufen FeO und Fe_2O_3 werden dabei aber an Reduktionskohlenstoff 214 kg und 320 kg/t Fe und an Zusatzwärme 659 000 und 1 016 000 kcal/t Fe gebraucht, weil die bei der Verbrennung von Kohlenstoff durch den Erzsauerstoff zu Kohlenoxyd freiwerdende Wärme nicht ausreicht (direkte Reduktion).

Die dritte Möglichkeit ist die, dass die Hälfte des Erzsauerstoffes direkt reduziert wird und das gebildete Kohlenoxyd die andere Hälfte indirekt reduziert. Als Gesamtwirkung wird also Erzsauerstoff durch Kohlenstoff zu Kohlensäure gebunden. Die Hälfte des Erzsauerstoffes braucht also weder zusätzlichen Kohlenstoff, noch Wärme. Man kommt also mit dem halben Kohlenstoff und Wärmebedarf der direkten Reduktion aus. (50% indirekte Reduktion.)

Man bezeichnet diesen Fall, wie er sich im Mittel etwa bei vielen Möllern einstellt, als 50% indirekte Reduktion. Dem in diesem Falle einschliesslich der Reduktion von Silizium, Mangan und Phosphor entsprechenden Bedarf von 160 kg Kohlenstoff/t Roheisen aus Erz steht der praktisch notwendige Wärmeaufwand von etwa 800 kg Kohlenstoff (1000 kg Koks) gegenüber. Davon dienen 5% zur Kohlung, 20% zur Reduktion und die übrigen 75% für Beheizung des Ofens durch Verbrennung vor den Formen. Er verbrennt bei der hohen Temperatur nur zu Kohlenoxyd, man erhält also nur 2412 kcal/kg Heizkohlenstoff frei, mit denen der zusätzliche Bedarf für die Reduktion (506 kcal)[1], für die fühlbare Eisen- und Schlackenwärme (560 kcal), für Austreibung von Kohlensäure und Wasser (290 kcal), für Kühlverlust (225 kcal) und die fühlbare Wärme im Abgas (397 kcal) gedeckt wird. Kohlenstoff

[1] Sämtliche Verbrauchsangaben (Angaben für 1 kg Roheisen) beziehen sich hier und später auf das Beispiel eines Thomashochofens mit 50% indirekter Reduktion, 600° Windtemperatur, 300° Abgastemperatur, 970 kg Koks/t Roheisen aus Erz mit 82% Kohlenstoff.

mit feuchter Luft in kaltem Zustand verbrannt, würde nur eine Temperatur von 1315° ergeben. Sie liegt unter der Temperatur des abgestochenen Eisens und der Schlacke und so niedrig, dass die direkte Reduktion sich dabei nur sehr langsam auswirken würde. Hier zeigt sich die Bedeutung des Gegenstromweges des Kokses mit dem Möller gegen das abziehende Abgas, die nicht allein in der für die Durchgasung des Erzes wesentlichen Auflockerung der Beschickungssäule besteht, sondern auch in der Vorwärmung des

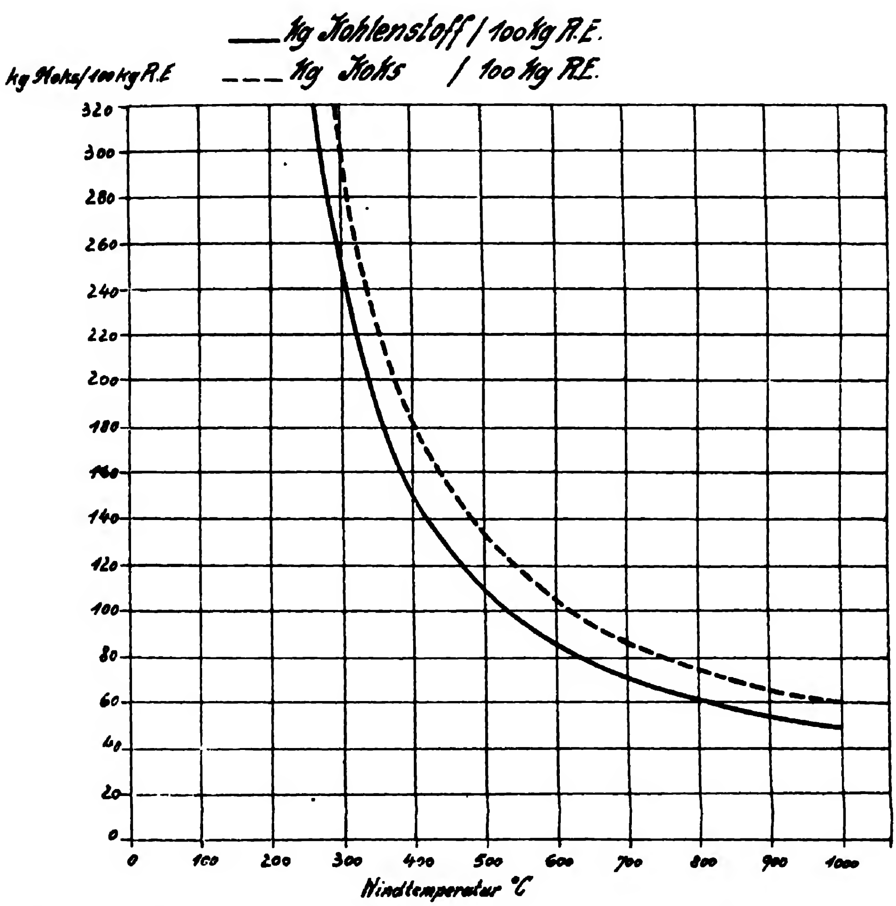

Abb. 1. Abhängigkeit des Koksverbrauches von der Windtemperatur.

Kokses auf Gestelltemperatur beruht. Für 100° Koksvorwärmung steigt die bei der Verbrennung des Kokses verfügbare Wärmemenge um 40 bis 50 kcal und die Verbrennungstemperatur um 25°, sodass man bei Vorwärmung des Kokses auf Gestelltemperatur bereits 600 bis 700 kcal/kg C über der Verbrennungswärme verfügbar hat. Also auch im Hochofen gilt die ausschlaggebende

Bedeutung des Regenerativverfahrens wie im Siemens-Martinofen. Erst durch die Vorwärmung des Brennstoffes durch die Abhitze erhält man überhaupt ein Wärmenutzgefälle für die Arbeit im Herd. Deshalb kann man auch mit kaltem Winde einen Hochofenprozess, wenn auch mit hohem Koksdurchsatz, durchführen. Diese wesentliche Bedeutung erklärt aber auch in einfacher Weise die ausserordentliche Senkung des Koksverbrauches, wenn man auch die Luft vorwärmt. Der Vorgang wird durch Abb. 1 erläutert. Man erhält je 100° Windtemperatur eine zusätzliche Wärmemenge von 140 kcal und eine Steigerung der theoretischen Verbrennungstemperatur um 70°. Infolgedessen steigt der Koksverbrauch stark bei fallender Windtemperatur. Bei Änderung des Reduktionsverhältnisses kann und wird die Steigerung praktisch nach beiden Richtungen natürlich

TAFEL I

ZUSAMMENSETZUNG DES GICHTGASES

m^3 Gas/1 kg Thomasroheisen aus:

	Moller		Wasserzersetzung (Luftfeuchtigkeit)		Koksschwelung		Reduktionskohlenstoff 50% indirekte Reduktion		Koksvergasung durch den Wind		Summe der Gasbestandtei	
	m^3	%	m^3	%	m^3	%	m^3	%	m^3	%	m^3	%
CO_2	0,0433	100					0,3	100			0,3433	9,2
CO			0,035	50					1,126	34,2	1,1610	31,2
H_2			0,035	50	0,035	78					0,0700	1,9
N_2					0,016	22			2,13	65,8	2,1460	57,7
Sa	0,0433	100	0,070	100	0,051	100	0,3	100	3,256	100,0	3,7203	100,0
Anteil am Gesamtgas		1,2		1,9		1,4		8,0		87,5		100,0

Abweichungen erfahren. 80% des Kokses verbrennen als Heizkoks vor den Formen durch den Wind, dazu werden etwa weitere 10% im Gestell und der unteren Rast durch direkte Reduktion verbraucht. Der Hochofenkoks muss möglichst schwer verbrennlich und druckfest sein, damit er unverändert das Gestell erreicht.

Der Aufbau des Gases aus seinen Bestandteilen geht mengenmässig aus Tafel I hervor. Das verschiedene Verhältnis von Reduktionsgas und Verbrennungsgas bestimmt die Gasanalyse. Den weiten Bereich der Streuung von 100 bis 0% direkter Reduktion und bei 60 bis 150 kg Kokssatz/100 kg Roheisen zeigt Abb.2. Kennzeichnend ist steigender Stickstoff und Kohlensäure-, fallender Kohlenoxydgehalt. Praktisch wird diese den Hochofen in seiner Eigenschaft als Gaserzeugung kennzeichnende Streuung durch die beobachtete Spanne von etwa 70% bis 30% direkter Reduktion

und durch Kokssätze von 80 bis 120 kg/100 kg Roheisen begrenzt. In diesem Bereich liegt der Gehalt an Kohlensäure von (5,0% bis 8,2%) bis (8,9% bis 13%), an Kohlenoxyd von (35% bis 36%) bis (25% bis 28%), Werte, wie sie die Praxis stündlich und täglich

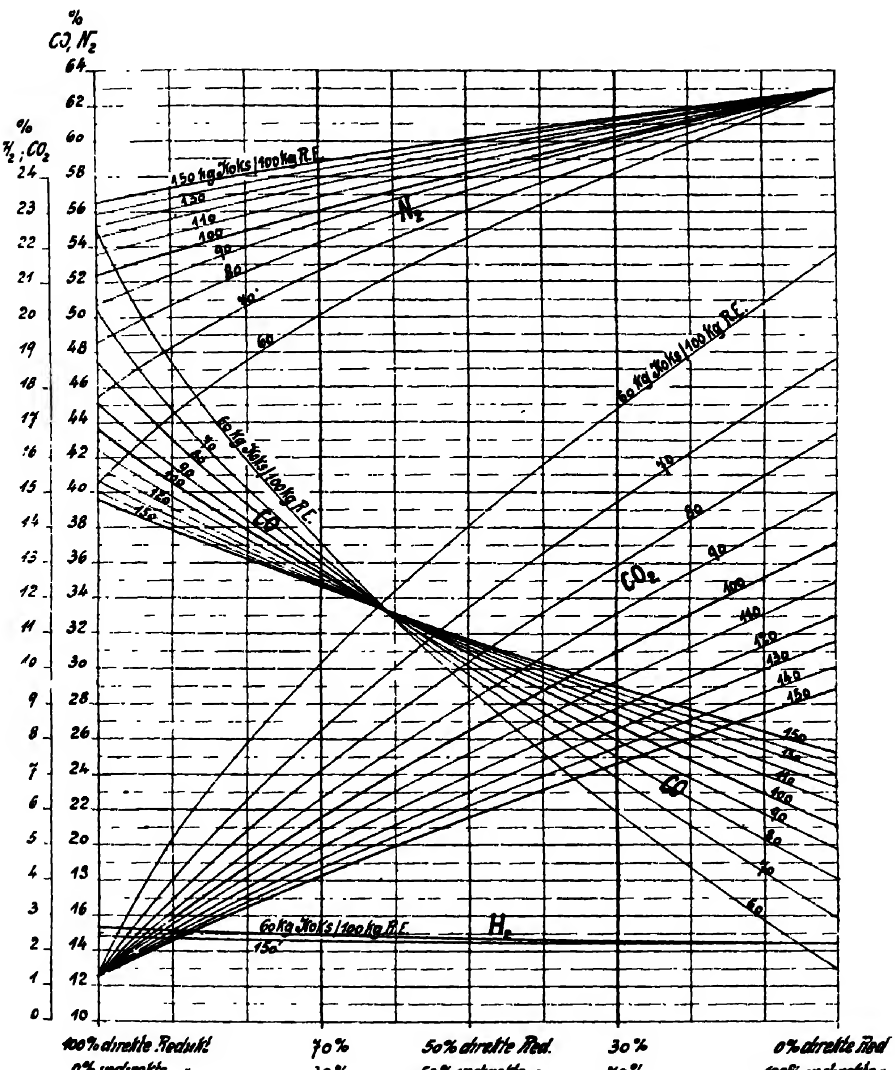

Abb. 2. Abhängigkeit der Gasanalyse vom Kokssatz und vom Reduktionsverhältnis.

zeigt. Bei 80 kg Kokssatz findet man das von Bell als erreichbaren Grenzwert angegebene Verhältnis von $\frac{CO}{CO_2} = \frac{2}{1}$ bei etwa 70%

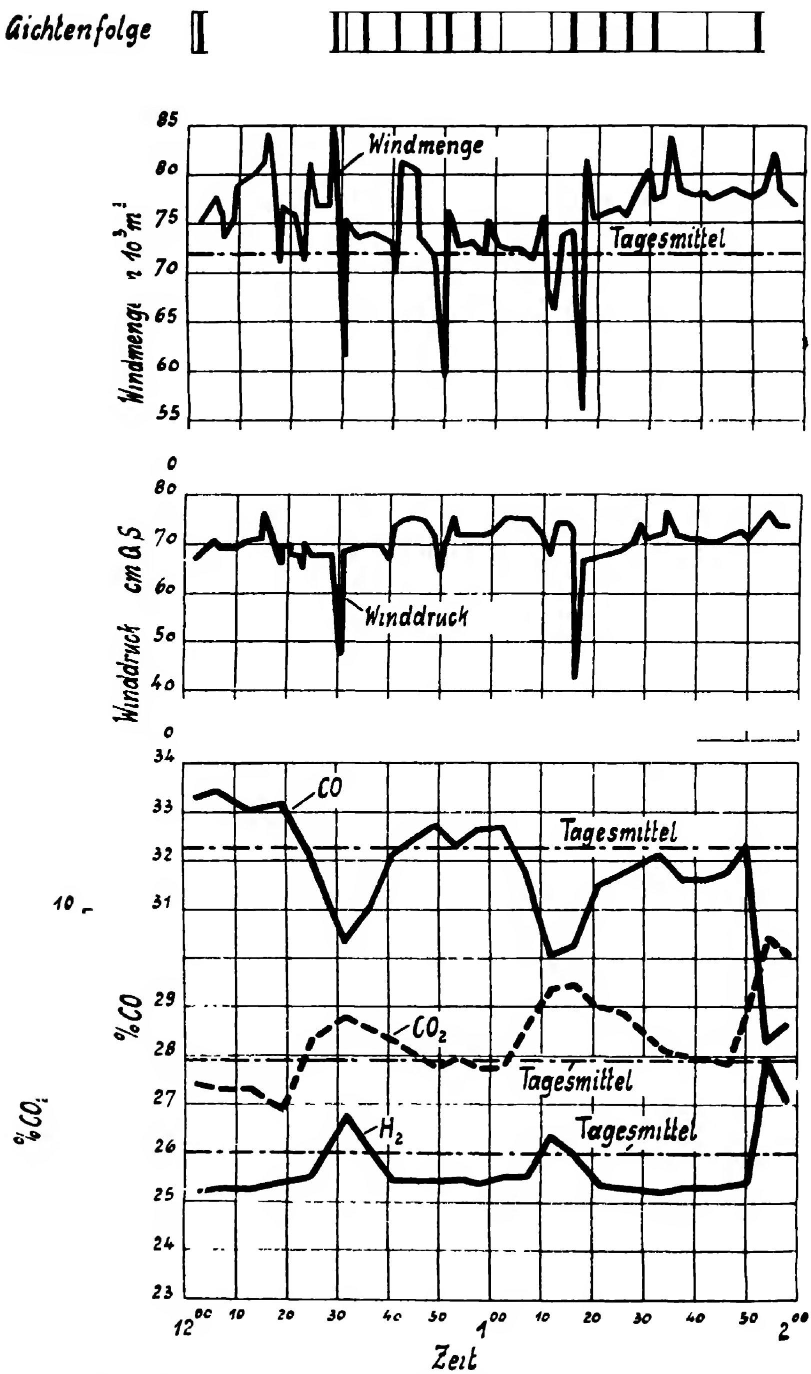

Abb. 3. Die Grundlagen der laufenden Betriebsüberwachung.

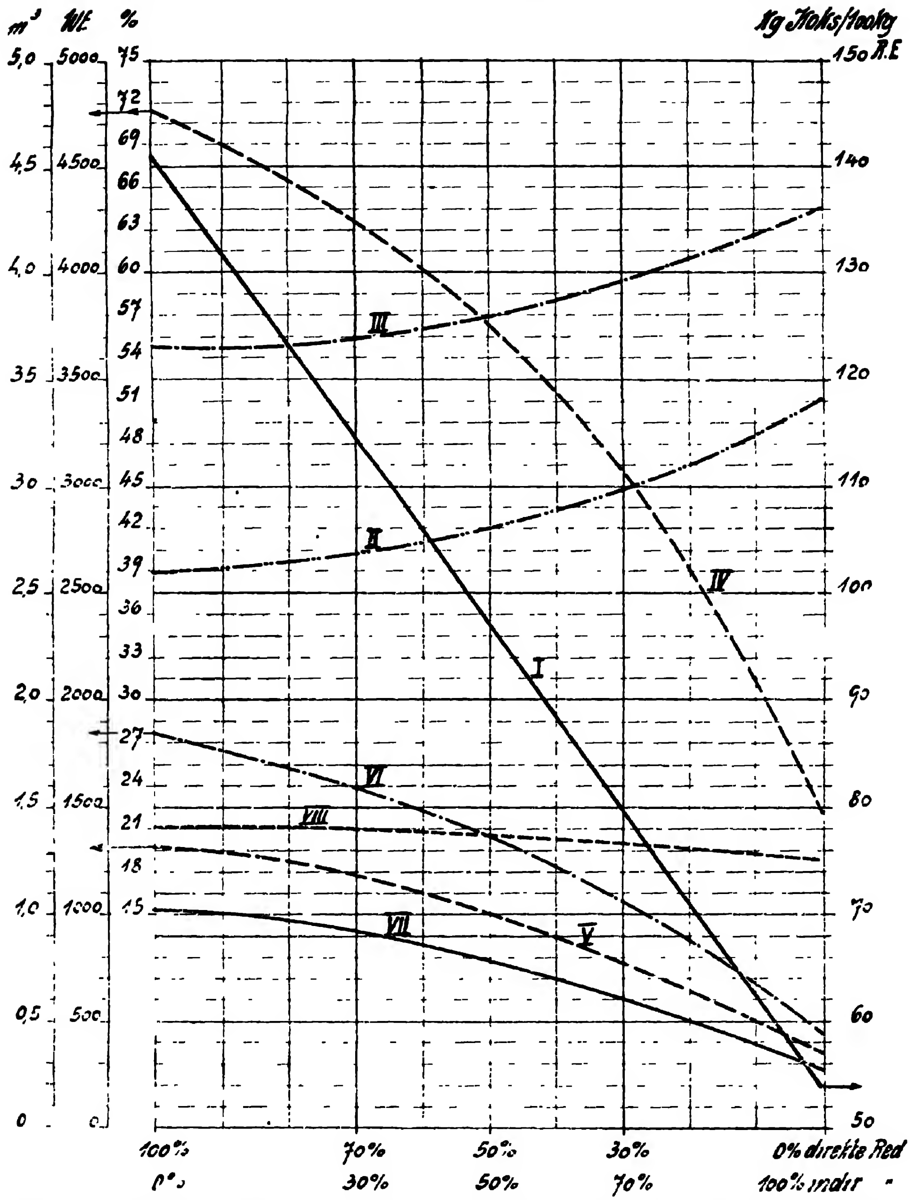

Abb. 4. Abhängigkeit des Koksverbrauches und der Gaserzeugung von dem Reduktionsverhältnis.

(*Thomasroheisen. 600° C Windtemperatur. 300° C Abgastemperatur. 70 kg Schlacke/100 kg Roheisen.*)

I	kg Koks/100 kg R.E.	
II	m³ Wind/kg Koks.	
III	m³ Gas/kg Koks.	
IV	Gasheizwertausbringen in WE/kg Koks.	2 Ablesungen
,,	in % des Koksheizwertes	
V	Heizwert des Gichtgases	
VI	Gasheizwertausbringen in WE/m³ eingeblasenen Wind	
VII	Verbrennungsluftbedarf in m³/m³ Gichtgas	
VIII	m³ Gas/m³ Wind	

indirekter Reduktion. Günstigere Werte sind wohl kaum beobachtet worden.

Die starken laufenden Schwankungen der Gasanalyse im Betriebe zeigt Abb.3. Sie sind die Folge der schwankenden Kohlenstoffzufuhr bei dem um ±10% schwankenden Schüttgewicht und den in gleichen Grenzen schwankenden Kohlenstoffgehalt des Kokses, sowie der Veränderung des Reduktionsverhältnisses infolge Veränderung der Temperatur an der Grenze von indirekter und direkter Reduktion und der Gasberührung.

Den Einfluss des verschiedenen Reduktionsverhältnisses für einen Hochofenprozess nach Fussnote 1 zeigt Abb. 4. Der Koksverbrauch ist bei dem mittleren Fall von 50% indirekter Reduktion 97,0 kg je 100 kg Roheisen aus Erz, entspricht also üblichen Betriebsverhältnissen. Er würde bei reiner indirekter Reduktion nur 53,6 kg, bei dem praktisch günstigsten Falle von 70% indirekter Reduktion 80,0 kg betragen und bei reiner direkter Reduktion auf 145,0 kg steigen. Er wächst für 10% weniger indirekte Reduktion um 90 kg/t. Bei einer um ±100° Änderung der Abgastemperatur (300°) würde er sich um 40 bis 60 kg/t Roheisen, bei ±100° Änderung der Windtemperatur um 35 bis 50 kg/t Roheisen ändern.

Man sieht, wie tiefgreifend schon kleine Veränderungen auf den Ofengang wirken und erkennt die Notwendigkeit, alle irgendwie beherrschbaren Arbeitsbedingungen konstant zu halten. Im Hinblick auf den Hochofen als Gaserzeuger beachte man die Veränderungen im Bereiche von

	Kurve Nr.	30%	50%	70%
		indirekter Reduktion		
Heizwert kcal/m³	V	1180	1000	780
Gasheizwertausbringen in % des Koksheizwertes	IV	64	56	46
Gasheizwertausbringen kcal/m³ eingeblasenen Wind	VI	1600	1360	1060
m³ Wind/kg Koks	II	2,68	2,8	2,98
m³ Gas/m³ Wind	VIII	1,39	1,36	1,32

Man sieht Streuungen nach beiden Seiten von ±5 bis 20%. Ein idealer Gaserzeuger ist der Hochofen jedenfalls nicht, wenn man dazu berücksichtigt, dass die Aufnahme des Windes und damit die Gaserzeugung bei ungenügender Pressung der Maschinen stark von den ständig wechselnden Widerständen abhängig ist und um ±15% um das Mittel schwanken kann. Dies wird durch Abb.5 veranschaulicht, aus der man gut erkennen kann, wie plötzliche

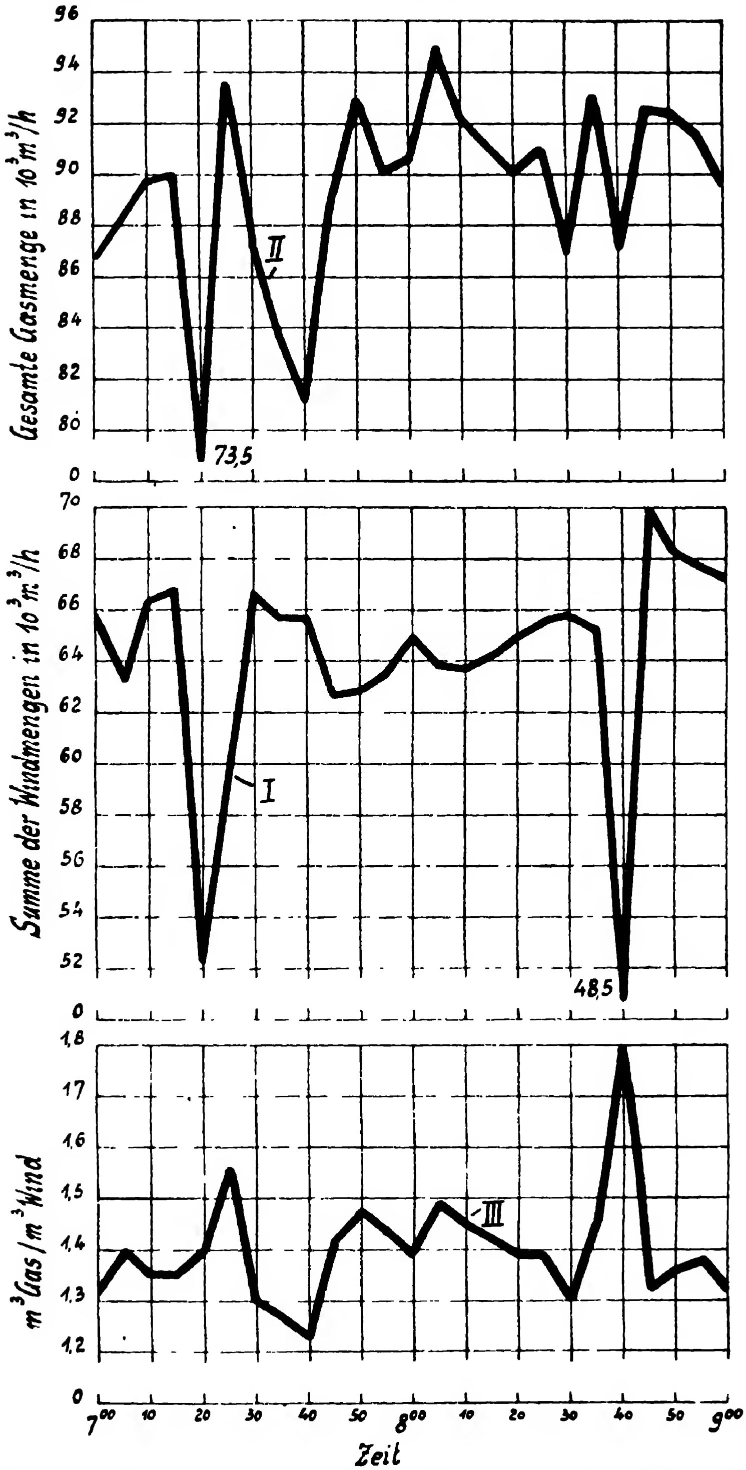

Abb. 5. Schwankungen der Beziehung von Gas- zur Windmenge.

Änderung der Windmenge das Verhältnis von Gasmenge zur Windmenge in weiten Grenzen ändert. Die Gasanalyse[2] ist ein vorzügliches Mittel zur Beurteilung des Hochofenganges, namentlich die Änderung des Stickstoff- und des Kohlensäuregehaltes geben den besten Anhalt. Im Zusammenhang mit der Windmenge kann man die wesentlichsten Vorgänge mit Hilfe von Abb.4 und Abb.5 erklären. Es lässt sich bei guter Beobachtung manches verbessern, das dem gleichmässigen Arbeiten des Hochofens als Gaserzeuger wie als metallurgische Einrichtung nützlich ist.

II.—*Die Reinigung.*– In Abhängigkeit von dem Feinheitsgrade der Erze und der Zerreiblichkeit des Kokses, sowie der Gasgeschwindigkeit an der Gicht, verstauben 2 bis 6, sogar bis 10% des Möllers, das sind 12 bis 60 g/m³ Gas.

Der Wasserdampfgehalt des Gases von 30 bis 60 g, der bei starkem Nässen der Gicht auch auf 100 g und darüber steigt, führt zu Niederschlägen und mit dem Staube zu Krustenbildung in Leitungen und Ventilen. Der Staub beeinträchtigt durch verschlackende Überzüge die Wärmeübertragung und verringert den Wirkungsgrad um 10 bis 20%.

Deshalb muss das Gas gereinigt und gekühlt werden.

Die Grobentstaubung erfolgt in Standrohren von 5 bis 10 m Durchmesser und 10 bis 20 m Höhe bei Geschwindigkeiten von möglichst unter 0,5 m/s auf 5 bis 15 g/m³ herunter. Zur Vorkühlung bei Nassreinigung von 150 bis 250° auf 30 bis 40° und zur Vorreinigung auf 0,5 bis 1,5 g dienen Standwäscher mit Holzhorden und Spritzdüsen mit aufsteigendem Gegenstrome des Gases. Die Belastung ist 100 bis 150 m³/m³ Kühlraum bei einem Wasserverbrauch von 2 bis 3 m³/1000m³ und einem Druckverlust von 50 mm WS. Die Feinreinigung erfolgt in Theisen-Waschern mit einem Kraftverbrauch von 5 bis 6 kWh/1000 m³ auf einem Reinheitsgrad von 0,01 g/m³ und weniger, bei einer Dauerbelastung von 85 000 m³/h, vorübergehend bis 100 000 m³/h und einem Wasserverbrauch von 0,7 m³/1000 m³. Der Leistungsgrad ist über 90%.

Die Trockengasreinigung nach Hallberg-Beth reinigt ohne Vorwascher durch die Filterschläuche von 10 g Staub/m³ auf 0,004 g/m³, braucht aber doch einen kleinen Standkühler zur Temperaturregelung auf ca 100° durch Wassereinspritzung, wobei bis 5 g

[2] Bansen, Hugo: *Beurteilung der Stoff- und Wärmebilanz des Hochofens nach der Gichtgasanalyse und der Windmenge.* Archiv für Eisenhüttenwesen, 1.Jg.1927/28, A 245.

Staub/m³ noch abgeschieden werden. Die Nennleistung eines Kastens von 36 000 m³/h wird in der Spitze erreicht. Der Leistungsgrad der Anlage beträgt aber infolge der Stillstände für Reparatur und Reinigung, sowie durch die Verstopfung der Filter nur 60 bis 75%. Der innere Kraftbedarf ist gering (0,25 bis 0,5 kWh/1000 m³), wie auch der Wasserbedarf der Temperaturregelung (0,18 m³/1000 m³), jedoch ist infolge des grossen Druckverlustes von 200 mm WS eine Druckerhöhung zur Weiterförderung des Gases um 200 mm mit einem Kraftbedarf von 2,2 bis 3,2 kWh/1000 m³ und eine Nachkühlung des Gases von 70° Austrittstemperatur auf 20° mit 2,5 bis 3,00 m³ Wasser/1000 m³ Gas erforderlich, um ein wirklich trockenes Gas fur einen störungsfreien Leitungs- und Feuerungsbetrieb zu erhalten.

Die Nasswäsche braucht gegenüber der gleichwertigen Filteranlage mit Nachkühlung und Druckerhöhung bis 150 % mehr an Strom und erfordert eine Kläranlage. Sie braucht aber wenig Wartung und Reparatur (M 0,15/1000 m³ gegen M 0,21/1000 m³), hat nur die halben Anlagekosten, bezogen auf Nennleistung, (4000 M/1000 m³ gegen 8000 M/1000 m³) und nur $\frac{1}{3}$ derselben bezogen auf Betriebsleistung. Das gleiche gilt für den Platzbedarf. An Raum braucht sie nur den zwanzigsten Teil. Die elektrische Gasreinigung hat einen geringen inneren Stromverbrauch. Sie erfordert jedoch zur Vervollständigung dieselben Einrichtungen wie die Trockengasreinigung. Die Leistung fällt wesentlich mit steigendem Reinheitsgrad. Filter und elektr. Gasreinigung haben bei Wassermangel den Vorzug, wenn man den Nachteil des ungekühlten Gases in Kauf nehmen will. Die Erhaltung der Gaswärme ist kein ernstlicher Vorteil. Sie verschwindet bei längerer Leitung, erhöht nur den Druckverlust, erschwert die Messung und führt zu Wasserabscheidungen beim Unterschreiten des Taupunktes.

III.—*Die Verteilung.*—Da die Stossverluste in den Rohrleitungen bei Richtungswechseln und Übergängen neben den Reibungsverlusten den grösseren Teil des Druckverlustes ausmachen,[3] so sind scharfkantige Knie und Übergänge zu vermeiden und die Leitungen gradlinig zu führen. Die Geschwindigkeit (0°,760 mm) soll daher in Krümmern 8 m/s nicht überschreiten. Sie kann in graden, blanken Leitungen von 200 bis 300 mm ϕ bis 10 m/s und bei Rohrleitungen von über 1000 mm ϕ bis 20 m/s gewählt werden, jedoch

[3] Bansen, Hugo; Rheinhausen-Nrh.: *Berechnung des Druckabfalls in Gasleitungen und gemauerten Kanälen*, Archiv für Eisenhüttenwesen, 1.Jg. 1927/28, S: 187.

ist zu beachten, dass Nietnähte und Verkrustungen den Widerstand auf das 2 bis 3-fache steigern und bei heissen Gasen die Widerstände mit $(1 + \alpha\ t)$ steigen. Eckventilen sind 2 Plattenschieber mit reichlicher Zwischenentlüftung und Wellrohrkompensatoren vorzuziehen. Infolge des Druckverlustes ist in langen Leitungen bei wechselnder Gasentnahme in den einzelnen Verbrauchszweigen auch bei Zwischenschaltung eines Gasometers kein gleichbleibender Gasdruck zu erzielen. Dieser ist aber zur Aufrechterhaltung der Gaszufuhr für eine einmal eingestellte Ofen- oder Maschinenbelastung erste Vorbedingung. Daher ist der Einbau von Druckreglern in Hauptabzweigen und vor grösseren Verbrauchstellen erforderlich. Reicht der Gasdruck vor einer Zweigstelle für eine gleichmässige Zufuhr bei gesteigerter Entnahme nicht aus, so ist es besser, dort einen Zwischenventilator zur Druckerhöhung um 100 bis 200 mm aufzustellen, als den Gesamtdruck zu erhöhen. Zur Regelung ist eine Drosselklappe in aussenliegender Kugellagerung zu wählen. Die Steuerung erfolgt am besten durch Tauchglocken von 1 m^2 Fläche = 1 kg Verstellkraft für 1 mm WS und Zuleitungen von 150 mm ϕ zum raschen Ausgleich oder durch elektrische oder hydraulische Steuerwerke.

Bei Öfen, die häufig entsprechend der Beanspruchung eingestellt werden mussen, empfiehlt sich der Einbau eines Reglers für die Luftmenge nach der Gasmenge, namentlich dort, wo mehrere Brenner zugleich zu betätigen sind oder wo man mit 2 Gasen arbeitet.

IV.—*Die Verbrennung.*—Während man bei z.B. zwischen 50 und 100 mm schwankendem Gasdruck die Luftmenge auf die grösste Gasmenge, also auf einen mittleren Luftüberschuss von 25 bis 30% einstellen muss, kann man bei konstantem Gasdruck mit 0 bis 10% Luftuberschuss arbeiten. Für + 10% Luftüberschuss fällt etwa der Kohlensäuregehalt um 1%, die Verbrennungstemperatur um 50°, die tatsächliche Ofentemperatur um 30 bis 40°, die Ofenleistung um 3 bis 10%, die Abgasmenge und damit der Abgasverlust steigen um 5%; da zugleich aber die Abgastemperatur um 30 bis 50° steigt, so nimmt er um 10% und mehr zu. Je inniger man Gas und Luft mischt, je höher man sie vorwärmt und je kürzer man die Verbrennungsstrecke durch Aufwickeln der Gas- und Luftstrahlen durch Torsionsbrenner macht, um so vollkommener wird die Verbrennung bei Verkleinerung des Verbrennungsraumes und Steigerung der Flammen- und Ofentemperatur. Führt man, wie z.B. bei Winderhitzern oder alten Kesselbrennern, Gas und Luft in dicken Strahlen nebeneinander gradlinig ein, so

braucht man einen Verbrennungsweg von 10 bis 20 m bis zum Verschwinden des Kohlenoxydes u. erzielt Leistungen von 150 000 bis 300 000 kcal/1 m^3 Verbrennungsraum; bei stärkerer Unterteilung der Gas- und Luftkanäle in Ofenköpfen steigt die Leistung auf 1 000 000 kcal/m^3/h bei 3 bis 5 m Verbrennungsstrecke; bei Torsionsbrennern erreicht man aber 15 000 000 kcal/m^3 und mehr bei bereits 40 bis 50% Verbrennung an der Brennermündung und völliger Verbrennung auf 1 m Brennerlänge. Der Temperaturfaktor[4] steigt um 10 bis 15%, die Flammentemperatur also um 150 bis 200° und die Ofentemperatur um 100 bis 150°, sodass man bereits mit kaltem Gichtgas Arbeitstemperaturen von 1200 bis 1300° erzielen kann.

Wärmt man bei Gichtgasfeuerung die Luft oder das Gas vor, so erzielt man für 100° Vorwärmung je eine Wärmezufuhr von etwa 30 kcal m^3 Gas und eine Erhöhung der Verbrennungstemperatur um je etwa 40°. Die Abgastemperatur sinkt um 60 bis 70° je 100° Gas- oder Luftvorwärmung je nach dem Wirkungsgrade des Wärmeaustauschers. Nutzt man z.B. die mit 1000° abziehenden Abgase eines Stossofens zur Gas- und Luftvorwärmung bis 280° aus, so kann man aus 720° Temperaturgefälle Gas und Luft auf je 500 bis 600° erwärmen. Die Verbrennungstemperatur steigt dadurch von etwa 1500° (bei 10% Luftüberschuss) um 400° bis 480° auf 1900 bis 1980°, sodass man damit Ofentemperaturen von 1400 bis 1500°, wie bei Kohlenfeuerung, erreichen kann. Der Bruttowirkungsgrad steigt von $\frac{1500 - 1000}{1500°} = 0{,}33$ auf $\frac{1980 - 1000}{1500°} = 0{,}66$ also das doppelte, sodass man für Blockwärmöfen auf Gesamtwirkungsgrade von 50 bis 55% und auf Wärmeverbrauchszahlen von 350 000 bis 400 000 kcal je t kalten Einsatz kommt.

Diese Steigerung des Wärmenutzgefälles durch die Wärmeumformung ist von umso grösserer Bedeutung, je höher die Arbeitstemperatur des Werkstückes ist und gestattet es, jeden Brennstoff den höchsten Anforderungen anzupassen. Man könnte bei Vorwärmung auf 1300° damit einen Siemens-Martinofen beheizen, wenn die Strahlung der Flamme ausreichen würde.

Diesen Mangel gleicht die Beimengung von Koksofengas aus, das je nach der Stärke des Gemisches jede Temperatur erreichen lässt. Ein Zusatz von 20% (1540 kcal) genügt, um mit Luftvorwärmung auf 600° allein dasselbe zu erzielen, wie mit zusätzlicher Gichtgasvorwärmung. Mit kaltem Mischgas, im Verhältnis von 2 m^3 Gichtgas

[4] **Bansen, Hugo, Rheinhausen-Nrh.:** ***Errechnung der Arbeitstemperaturen in metallurgischen Öfen*****, St. u. E. Nr. 7, Februar 1922.**

zu 1 m^3 Koksofengas, erzielt man mit kalter Luft im Torsionsbrenner das gleiche.

Die Verwendung von Koksgas zur Anreicherung gibt die Möglichkeit, in einfacher Weise jede Feuerung durch Anbau von Gasbrennern auf Gas umzustellen und durch Steigerung des Zusatzes auf jede gewünschte Temperatur und Leistung zu bringen. Man kann das gleiche auch durch Zusatz von Teer oder Teeröl oder Kohlenstaub erreichen, jedoch ist die Einstellbarkeit nicht so sicher und bei Kohlenstaub die Einrichtung weniger einfach.

Grundsätzlich ist die Anwendung von Ventilatorluft für Gasfeuerungen zu empfehlen, weil sie in Unabhängigkeit der Bemessung der Querschnitte erst die Steigerung der Ofenleistung durch verstärkte Beheizung ermöglicht und allein eine gute Regelbarkeit auch bei Verstopfungen von Kammern und Brennern zulässt.

Die gesuchte Einfachheit des Brenners durch seine Ausbildung als Strahlgebläse zum Ansaugen der Luft kann bei Öfen zu keinem vollen Erfolge führen, da er unter Überdruck stehen muss, der Wirkungsgrad als Fördermittel sehr gering ist und man auf die gute Durchwirbelung verzichten muss. Wird gar ein Teil der Luft unter höherem Druck verwendet, so hat der Strahlbrenner überhaupt seinen eigentlichen Sinn verloren, weil doch eine Luftleitung erforderlich ist und der Energieaufwand geringer ist, um die ganze Luft unter einen Druck von 50 bis 100 mm WS zu setzen. Besonders einfach wird die Anlage, wenn man einen Ventilator oder Luttengebläse direkt an den Ofen oder auf das Luftventil setzt. Zur Sicherung sind in die Gasleitungen Klappen einzubauen, die das Gas absperren, wenn die Verbrennungsluft ausbleibt.

V.—*Die Winderhitzung.*—Der Winderhitzerbetrieb mit schlecht gereinigtem Gase und schwankendem Gasdruck brauchte zur Sicherung der Windtemperatur reichliche Speichermöglichkeit durch Anwendung von 4 und mehr Apparaten, lange Aufheizzeiten und weite Kanäle wegen der Verschlackung. Das Arbeiten mit bestgereinigtem Gase gestattet die Anwendung gut schliessender Schieberarmaturen, die auch mit Druckluft und automatisch zur raschesten Umsteuerung betätigt werden können. Infolgedessen werden lange Aufheizzeiten überflüssig und eine Umstellzeit von 1 Stunde und weniger möglich. Das reine Gas gestattet die Anwendung von engen Kanälen. Der Weg geht von 160 mm Kanalweite über 100 bis 80 mm auf immer kleinere Abmessungen bei steter Vergrösserung der Heizflächenleistung. Soll das Steingewicht voll ausgenutzt werden, so muss die Wandstärke mit Kanalweite und Umstellzeit abnehmen. Bei

Steinstärken von 30 mm und darunter gelangt man so von 10 bis 15 m^2 Heizfläche/m^3 Gitterraum auf 30 bis 50 m^2/m^3. Statt 7000 m^2 Heizfläche und 750 t Gittergewicht von geringem Wirkungsgrade bringt man in dem gleichen Apparat 14 000 m^2 mit nur 400 bis 500 t Gewicht unter, das bei voller Ausnutzung die gleiche Speicherfähigkeit besitzt und durchaus genügt, um für hohe Erzeugungen mit 1 Apparat auf Gas und 1 auf Wind auszukommen. Der nutzbare Auftrieb in einem Winderhitzer von 35 m Höhe mit einem Kamin von 80 m Höhe ist jedoch bei 300° Abgastemperatur nur 35 mm WS und sinkt noch mit abnehmender Abgastemperatur. Man kann auch bei Beseitigung überflüssiger Übergangswiderstände nur 12000 bis 15000 m^3 Gas/h aufheizen. Führt man aber die Verbrennungsluft und das Gas mit einem Vordruck von 100 bis 200 mm ein, so kann man die Gasmenge verdoppeln, kann die Beheizung beliebig zur Aufholung auf höhere Temperaturen verstärken und gleichmässiger und besser regulieren. Die Störungen durch die Steigerung der Kuppeltemperatur auf 1300 bis 1400° bei starker Beheizung beseitigt man durch Arbeiten mit einem Luftüberschuss von 30 bis 40%, also nicht über 21% Kohlensäure im Abgas, sodass die Temperatur 1250° nicht überschreiten kann. Durch Isolation mit harten Kieselgursteinen und Verringerung der Apparatezahl senkt man die Wandverluste von 2000 000 kcal/h bei Vierapparatebetrieb auf 500 000 bei Zweiapparatebetrieb und hebt den Wirkungsgrad der Heizfläche von 90 auf 97%. Durch Wahl grosser Heizflächen und enger Kanäle fällt die Abgastemperatur von 250-350° auf 80 bis 200°; dadurch steigt der Wirkungsgrad der Feuerung von 0,8 auf 0,88. Der Gesamtwirkungsgrad steigt also von $0{,}9 \cdot 0{,}8 = 0{,}72$ auf $0{,}97 \cdot 0{,}88 = 0{,}85$. Der Gasverbrauch für 100° Windtemperatur = 32,4 kcal/m^3 Wind fällt damit von $\frac{32{,}4}{0{,}72} = 45$ kcal auf $\frac{32{,}4}{0{,}85} = 38$ kcal/m^3 Wind. Der Gasverbrauch fällt von 3,5 — 4% der Gaserzeugung/100° Windtemperatur auf 2,8%. Die Heisswindleitungen sind mit $\frac{1}{2}$ harten Kieselgurstein und 200 mm feuerfestem Futter auszumauern. Der Temperaturverlust bis zur Ringleitung beträgt dann nur 20°. Zur Regelung der Ringleitungstemperatur dient häufig Kaltwindzusatz, dessen Regelklappe zur Gleichhaltung der Temperatur automatisch zu steuern ist.

B. Die Kraftwirtschaft

I. —*Antriebsart.*—Trotz 25 bis 50% höheren Wärmeverbrauches macht die Dampfturbine zur Kraft- und Winderzeugung der Gasmaschine den Platz streitig. Sie ist ihr in Anlage- und Betriebskosten, Raum- und Leutebedarf wesentlich überlegen und

gestattet die Wahl grösserer Einheiten, während die Grossgasmaschine mit 3800 bis 4000 kW an einem gewissen Ende der Entwicklung steht. Jene ist bei einem Wärmeverbrauch von 4500 kcal/kWh bei einem Gaspreise von 0,233 Pf/1000 kcal der Gasmaschine an Wirtschaftlichkeit gleichwertig[5] und kommt bei Werken mit Gichtgasüberschuss allein in Frage.

Besonders günstig liegen die Verhältnisse bei Verwendung der Dampfturbine zum Antrieb von Gebläsemaschinen. Sie hat hier bei Belastungsschwankungen durch Drehzahlregulierung annähernd gleichen Wärmeverbrauch, der bei neuzeitlichen Turbinen und einem Vakuum von 96% (Kondensatorkühlung durch Flusswasser) auf 4100 bis 4200 kcal/kWh (einschl. des Eigenverbrauchs) gehalten werden kann. Selbst bei voller Bewertung des Wärmebedarfs ist dann das Dampfturbogebläse dem Gaskolbengebläse an Wirtschaftlichkeit überlegen. Das Gaskolbengebläse ist mit 3800 kW bei einer Windlieferung von 1650 bis 1300 bis 850 $m^3 \left(\frac{0°}{760}\right) / \text{min.}$ auf einen Druck von 1,0 bis 1,5 bis 2,5 atü an der Grenze. Im Dauerbetrieb ist sein Wirkungsgrad infolge undichter Kolben und Ventile nicht wesentlich besser als der eines Turbogebläses. Dieses kann z.B. durch Drehzahlregulierung von 2600 bis 3300 U/min und einem Leistungsbedarf von 4500 bis 8400 kW an der Gebläsekupplung dieselbe Windmenge $= 2400\ m^3 \left(\frac{0°}{760}\right) / \text{min.}$ von 1,0 bis 2,25 atü bei einem Wirkungsgradabfall des Gebläses von 73,8 auf nur 71,6% fördern. Bei maximaler Drehzahl und geringerem Druck als 2,25 atü ist die geförderte Windmenge noch entsprechend grösser.

In Zahlentafel II. ist nach Angaben von Wolf und Bartscherer[6] eine Gegenüberstellung von Gas- zu Dampfantrieb zusammengestellt.

II.—*Dampfkessel.*—Die älteren Flammrohrkessel von 10 bis 15 atü können eine Heizflächenbelastung von 25 bis 35 $kg/m^2/h$ (bis 55 kg/m^2 sind erreicht worden[7]) aufbringen und erreichen bei Verwendung von Wirbelbrennern und Economiser einen Wirkungsgrad von 65 bis 75 %. Bei der verhältnismässig kleinen Heizfläche ($\sim 100\ m^2$) und der geringen Belastung je Einheit ist der Raumbedarf gross.

[5] Bartscherer: *Gasmaschine oder Dampfturbine*, Archiv f. Eisenhüttenwesen, Jg. 1, 1927/28, D 297.

[6] Wolf, Hermann und Bartscherer. *Gasmaschine oder Dampfturbine*, Archiv für Eisenhüttenwesen, 1927, Heft 4, D 285 und 297.

[7] Bansen, Hugo, Rheinhausen-Nrh.: *Glückauf*, 1927.

TAFEL II.

GEGENÜBERSTELLUNG GAS- ZU DAMPFANTRIEB.

	Stromerzeugung.[1]		Gebläse.[2]	
	Gas.	Dampf.	Gas.	Dampf.
Max. Leistung ... ... kW	4000	bis zu sehr grossen Einheiten.	4000	bis zu sehr grossen Einheiten.
Anlagekosten:[3]				
Gasmaschine je 4000 kW ohne Abhitzekessel ... Mk/kW	332			
Gasmaschine je 4000 kW mit Abhitzekessel ... Mk/kW	355		350	
Abhitzeturbine ... ... ,,	130		115	
Dampfturbine		224		188
Wärmeverbrauch[4]: kcal/kWh		4500		4100
ohne Abhitzekessel	4000		4000	
mit ,, ...	3000		3000	
Adiab. Wirkungsgrad d. Gebläses %			85	81[5]
Betriebskosten ... Pf/kWh	0,5	0,35	0,5	0,2
Platzbedarf	2,5 : 1		2,5 : 1	

[1] nach Bartscherer } Archiv f.d. Eisenhüttenwesen 1927, Heft 4, S.
[2] ,, Wolf } 285 u. 297.
[3] Die Anlagekosten sind auf inst. kW bezogen.
[4] In den Wärmeverbrauchszahlen ist der Verbrauch der Hilfsmaschinen eingerechnet.
[5] Adiab. Wirkungsgrad des Turbo-Gebläses erscheint etwas hoch.

In dem Bestreben, eine grössere Dampfleistung auf beschränkterem Raum bei besserem Wirkungsgrad zu vereinigen, entstand einer neuer Kesseltyp,[8] der aus einem Oberkessel mit 5 Flammrohren und einem Unterkessel mit Rauchrohren und eingebautem Überhitzer besteht.

Denselben Vorteil einer gedrängten Bauart bietet der Schiffskessel,[9] der 300 bis 350 kg Dampf je m² bebauter Fläche aufzubringen vermag. Enge Rauchrohre, die hier im selben Kessel oberhalb zweier Flammrohre liegen, in Verbindung mit einer Saugzuganlage, ermöglichen die Unterbringung einer grossen Heizfläche auf beschränktem Raum. Luftvorwärmer an Stelle eines Economisers und Wirbelbrenner sorgen für hohe Anfangstemperaturen und hohe Belastung der im Verhältnis zur Gesamtheizfläche geringen Heizfläche der Flammrohre. Der Überhitzer ist auch hier in die Rauchrohre verlegt.

[8] *Stahl und Eisen* 1925, Seite 1225 und 1926 Seite 1383.
[9] Vgl. Archiv für Eisenhüttenwesen, Heft 4, 1. Jg.: *Gasmaschine oder Dampfturbine.*

Die Betriebsergebnisse eines solchen Kessels von 250 m² Heizfläche sind in Abb. 6 schaubildlich dargestellt. Bei 15 atü, 350 bis 380° Dampftemperatur und einer Heizflächenbelastung von 35 bis 50 kg/m² wird ein Kesselwirkungsgrad von 80 bis 83% erreicht. Der Preis beträgt M 240.–/m² Kesselheizfläche und M 500.–/m² für die

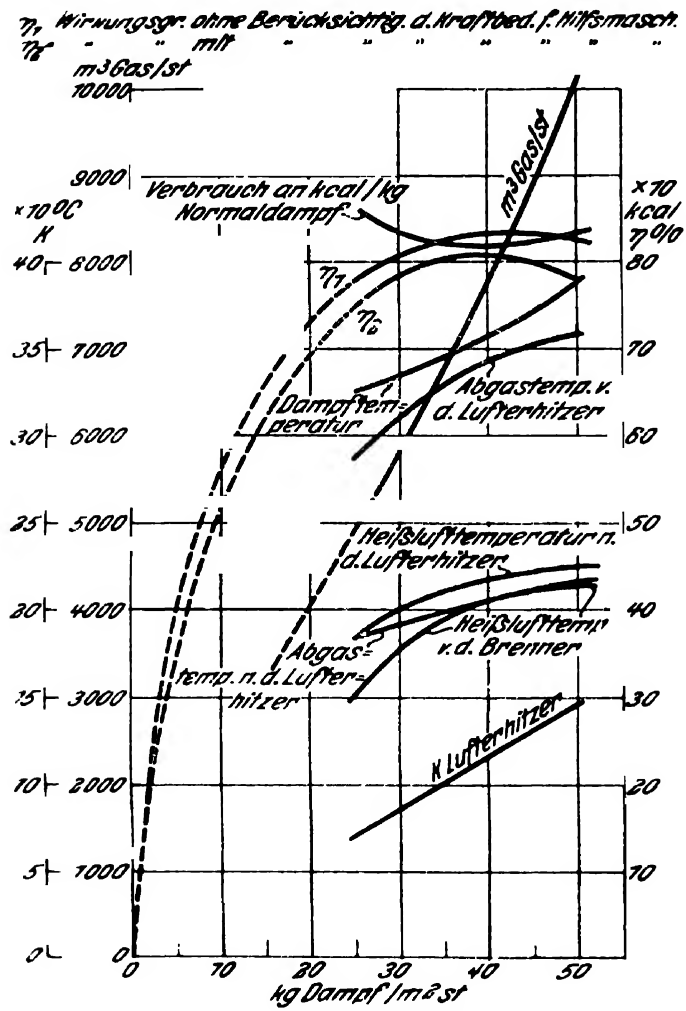

Abb. 6. Betriebsergebnisse eines Schiffskessels mit Gichtgasbeheizung

Gesamtanlage, entsprechend M 10 000.-/t stündlich und maximal erreichbarer Dampfmenge.

Bei grösseren Einheiten gelangt man schliesslich bei Gas- und Luftvorwärmung zu dem Steilrohrstrahlungskessel, der bei 35 atü und 400° Dampftemperatur eine Heizflächenbelastung von etwa 80 kg/m² bei 80 bis 86 % Wirkungsgrad aufzubringen vermag. Zur

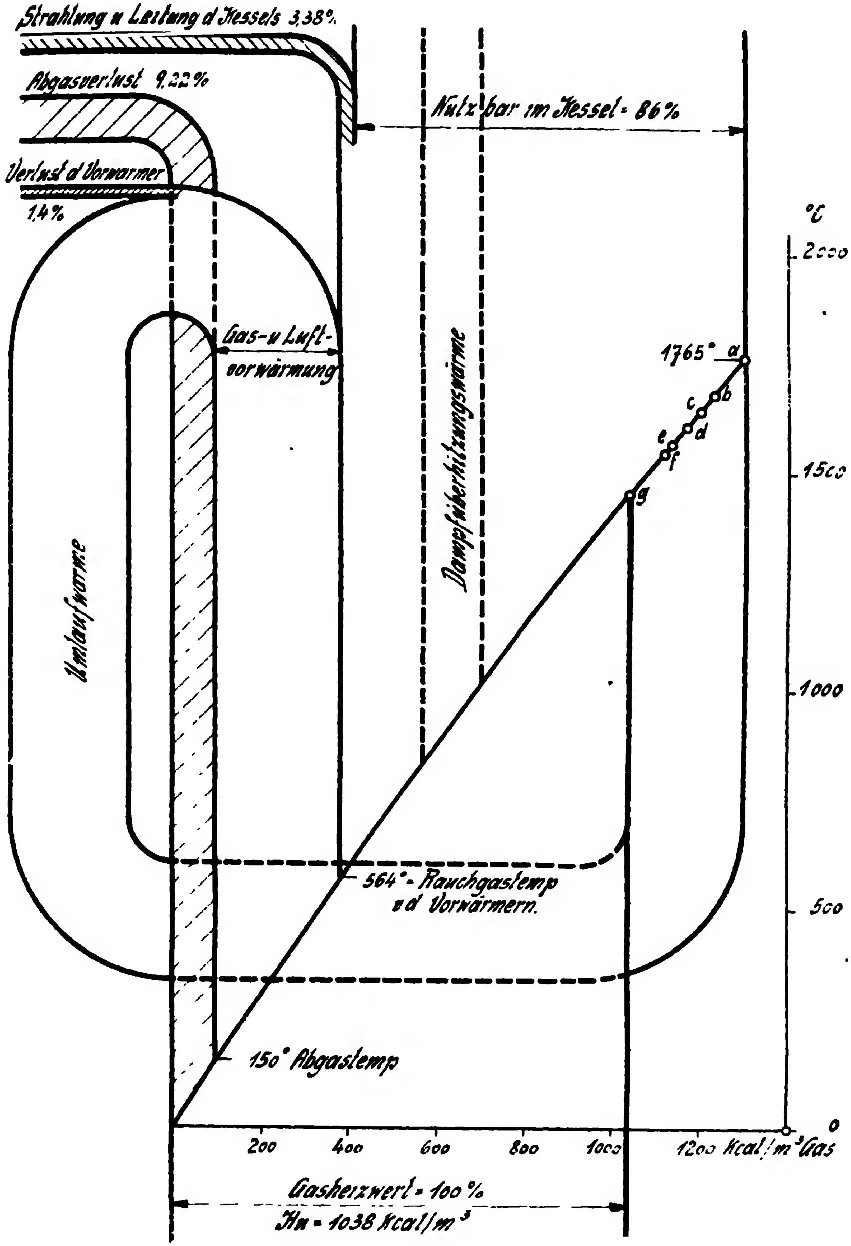

Abb. 7. Wärmestrombild und Wärmeinhalt-Temperaturschaubild in einem gichtgasbeheizten Kessel bei Gas- und Luftvorwärmung auf 400° und 23,8% Luftüberschuss.

Erreichung der hohen Heizflächenbelastungen ist auch hier eine Saugzuganlage erforderlich.

In Abb.7 ist der Wärmefluss und das Wärmeinhalt-Temperaturschaubild eines solchen Kessels bei Gas- und Luftvorwärmung auf 400° dargestellt. Um den Vorteil der Gas- und Luftvorwärmung anschaulich zu machen, sind die theoretischen Verbrennungstemperaturen für verschiedene Vorwärmung eingetragen. Sie betragen bei einem unteren Heizwert des Gichtgases von 1038 kcal/m³:

(*a*)	bei Gas- und Luftvorwärmung	auf	400°	= 1765°
(*b*)	,, ,, ,,	,,	300°	= 1680°
(*c*)	,, ,, ,,	,,	250°	= 1640°
(*d*)	,, Luftvorwärmung	,,	400°	= 1608°
(*e*)	,, ,,	,,	300°	= 1570°
(*f*)	,, ,,	,,	250°	= 1545°
(*g*)	ohne Gas- und Luftvorwärmung			= 1450°

(*d*) und (*e*) hat nur theoretisches Interesse, da Luftvorwärmung auf 300° bis 400° eine höhere Abgastemperatur und somit einen schlechteren Wirkungsgrad bedingen würde. Für (*g*) ist ein Wirkungsgrad von 86% nur bei nachgeschaltetem Economiser möglich. Durch die Beimischung von Öl oder Kohlenstaub kann die Strahlung der Verbrennungsgase und somit die Heizflächenbelastung noch erhöht werden.

Die Anlagekosten für eine 35 Atmosphärenanlage betragen ca M 800.–/m² Heizfläche, entsprechend M 10 000.– je t stündlich und maximal erreichbarer Dampfmenge.

Eine Verdampferanlage, deren Brüdenwärme dem Speisewasser wieder zugute kommt, in Verbindung mit einer weiteren Speisewasservorwärmung durch Zwischendampf auf 135°, erhöht den Gesamtwirkungsgrad der Anlage um 5,2 %.

Bei reinen Kondensationsturbinen und einer Anrechnung des Brennstoffes zu 0,25 Pf/1000 kcal ist eine 35 Atmosphären- einer 18 Atmosphärenanlage wirtschaftlich gleichwertig, da der Gewinn an Brennstoff durch erhöhte Anlagekosten wieder ausgeglichen wird. Jedoch schon bei Zwischendampf-Speisewasservorwärmung neigt sich der Vorteil der 35 Atmosphärenanlage zu.

Grössere Wirtschaftlichkeit bei höherem Druck ergibt sich bei grösserer Zwischendampfentnahme oder bei Gegendruckturbinen. Da aber bei solchen Anlagen das Kondensat meistens nicht zurückgewonnen werden kann, wird die Speisewasseraufbereitung gewisse Schwierigkeiten bieten.

III.—*Abhitzekessel.*—Für Gasmaschinen ist ein Wärmeverbrauch von 3000 kcal/kWh nur nach Gutschrift des Abhitzedampfes (1,2 bis 1,5 kg/kWh) erreichbar. Die Kessel haben bei Speisewasservorwärmung und Überhitzer eine durchschnittliche Heizflächenbelastung von 15 bis 20 kg/m². Die Anlagekosten betragen bei 15 atü und 400° Dampfüberhitzung M 475/m² Heizfläche für die Gesamtanlage, entsprechend M 23 800/t stündlich und maximal erreichbarer Dampfmenge, also mehr als das doppelte von Frischgaskesseln. Auch die Betriebskosten sind 2 bis 3 Mal so gross.

Der Anfall von Abhitzedampf ist durch den Ausfall von Maschinen oder bei Reparaturen an Abhitzekesseln selbst unregelmässig, sodass ein ausschliesslich mit Abhitzedampf betriebenes Turboaggregat für die Aufnahme der Belastungsspitzen von beschränktem Wert wäre. Es würde namentlich gerade dann unzulänglich, wenn infolge Ausfalls von Maschinen seine Leistung steigen müsste und braucht daher Frischgaszusatzkessel.

IV.—*Die Winderzeugung.*—Das Dampf-Turbogebläse, das bei geringerem Kostenaufwand durch Drehzahlregulierung auch auf höheren Druck blasen kann, ermöglicht es bei Öfen mit hoher Erzeugung auch bei dichterem Ofengang dem Ofen eine gleichbleibende Windmenge zuzuführen.

Da die Gebläsemaschinen selten und die Gasmaschinen nie in ihrer Leistung dem Windbedarf eines Ofens entsprechen, so arbeitet man heute vielfach mit den Gebläsemaschinen auf eine Sammelleitung. Der Winddruck wird so hoch gehalten, dass er dem Bedarf des dichtesten Ofens entspricht. Der deshalb durchschnittlich höhere Kraftbedarf wird durch den höheren Belastungsfaktor mehr als ausgeglichen. Die Öfen entnehmen ihren Wind durch steuerbare Drosselklappen und werden völlig unabhängig vom Gebläsehaus. Da stets Winddruck auf der Hauptleitung steht, ist beim Stillsetzen eines Ofens jede Explosionsgefahr ausgeschlossen.

Dieselben Gesichtspunkte über Gas- oder Dampfantrieb gelten auch für Stahlwerksgebläse, für 2,5 bis 3,0 atü. Dampfturbogebläse erfordern geringeren Kostenaufwand trotz höheren Wärmebedarfs.

Als Kompressoren für Pressluft stehen auf Hüttenwerken gewöhnlich nur kleine Einheiten. Da sich die einzelnen Verbraucher erst allmählich herangebildet haben, wurden von Fall zu Fall kleine Kolbenkompressoren mit elektr. Antrieb aufgestellt. Bei einer Neuanlage dürfte es sich empfehlen, die Pressluftererzeugung zu zentralisieren, um Stromverbrauch und Bedienungskosten zu sparen.

C. Öfen und Feuerungen

I.—*Die Koksöfen und das Koksofengas.*—Die Entwicklung des Regenerativofens brachte auch die Möglichkeit der Beheizung mit Gichtgas durch Anordnung eines weiteren Kammerpaares für das Gas und Vergrösserung der Gaszüge. Durch Beibehaltung der Koksgasleitung und Düsen entsteht der Verbundofen, der wahlweise auf Schwach- oder Starkgas gesetzt werden kann.

Der Schwachgasofen hat die gleiche Entwicklung wie der Starkgasofen genommen mit Kammerhöhen bis 4 m und Längen bis 13 m. Mit Rücksicht auf die Stückigkeit des Kokses und die Ausbesserungsmöglichkeit geht man in der Kammerbreite jedoch, nicht unter 400 bis 430 mm. Die Zustellung erfolgt in Silikamaterial. Die Garungszeiten betragen 17 bis 24 Stunden je nach der Kokskohlenbeschaffenheit. Namentlich bei Hüttenkokereien, die ihre Kohle von verschiedenen Zechen beziehen, ist eine reichliche Bunker- und Mischanlage erforderlich, um ein gleichmässig arbeitendes Gemisch erzeugen zu können. Ebenso wie die Garungszeit ist auch der Wärmeverbrauch ausserordentlich von der Art der Kohle abhängig. Eine allgemein gültige Wärmeverbrauchsgewähr[10] ist daher nicht möglich. Die Versuche von Terres und seinen Mitarbeitern zeigen, wie der Wärmeverbrauch/kg Kohle bis 1000° um 300 kcal/kg in den Grenzen von 200 bis 400 kcal/kg streut. Der teilweise endotherme und exotherme Verlauf hat natürlich im Zusammenhang mit der durch die Heizgasmenge gegebenen Wärmezufuhr den verschiedensten Einfluss auf das Garwerden des Kokses und die Bildung der Nebenerzeugnisse.

Die Beheizung hat mit einem bestens gereinigten Gichtgas von konstantem Druck zu erfolgen. Den Heizwertschwankungen des Gases entsprechend muss die Gasmenge geregelt oder Koksgas zum Ausgleich zugesetzt werden. Durch Regelung der Saugung ist auf einen möglichst gleichbleibenden Heizwert von nicht unter 3800 kcal (Hu) zu fahren. Das Gesamtgas wird dem Stahl- und Walzwerk zugeführt. Ist kein Gasometer vorhanden, so wird ein Überschuss durch einen Überdruckregler der Kesselgasleitung zugeführt. Die Hüttenkokerei soll so bemessen sein, dass sie das nötige Gas zur Beheizung der Stahl- und Walzwerksöfen unter Beimischung von Gichtgas liefert. Wie später ausgeführt wird, ist es wirtschaftlich, Überschusserzeugung als Ferngas abzugeben. Eine Entschwefelung

[10] Rummel K. und Oestrich H.: *Wärmetechnische Bewertung und Überwachung von Kokereien*, Archiv für Eisenhüttenwesen, 1. Jg., 1927/28, A und D 403.

des Gases ist nicht nötig, jedoch ist für weitgehende Entfernung des Naphtalins der Leitungen wegen zu sorgen.

II.—*Die Siemens-Martinöfen.*—Das Heizverfahren im Siemens-Martinofen ist nach Bansen durch die Tatsache[11] gekennzeichnet, dass die Abzugstemperaturen der Rauchgase aus dem Ofenraum höher liegen als die theoretische Verbrennungstemperatur der meisten zu seiner Heizung verwendeten Gase bei Verbrennung mit kalter Luft. Man erhält also nur ein Wärmenutzgefälle durch die Umformung der Abgaswärme. Daher steigt bei Kammertemperaturen von 1000 bis 1200° die Ofenleistung um 20% ohne Änderung der Gaszufuhr, also entsprechend einer Senkung des Wärmeverbrauchs je t Stahl.[12]

Die Wärme wird im Ofenraum hauptsächlich durch Strahlung übertragen. Die Gasstrahlung von Kohlensäure und Wasserdampf reicht dazu nicht aus.

Eine besonders hohe Vorwärmung des Mischgases von Koksofengas und Hochofengas ist zur Abspaltung von fein verteiltem Kohlenstoff bei der Umsetzung von Methan mit Kohlensäure und Wasserdampf erforderlich, die bei einer Temperatur von über 1100° stark einsetzt.[13]

Die Eigenstrahlung der Verbrennungsgase des Mischgases, Kohlensäure und Wasserdampf, genügt nicht zur Wärmeübertragung. Der fein verteilte Kohlenstoff aber nimmt nach Schack mit geringstem Temperaturgefälle Wärme durch Berührung mit dem Rauchgas auf und strahlt sie weiter an Bad und Ofenwände ab.

Die Umstellung von mit Generatorgas geheizten Öfen auf Mischgas erfordert daher eine Vergrösserung der Gaskammerheizfläche und stärkere Beheizung durch etwa 40% des Rauchgases. Man verwendet ein Mischgas von etwa 1 m³ Koksgas und 2 m³ Gichtgas von etwa 2000 kcal (Hu). Die Mischung erfolgt entweder für alle Öfen gemeinsam durch Zusammenführen der Gase in eine Leitung, besser aber am Ofen selbst, sodass man nach Bedarf ein stärkeres Gemisch herstellen kann. Das Anheizen und Warmhalten kann durch Gichtgas allein erfolgen. Der Vordruck des Gases muss geregelt sein, sodass die gleichmässige Gaszufuhr gewährleistet ist

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[11] Bansen, Hugo, Rheinhausen-Nrh.: *Leistung und Wirkungsgrad als Unterlagen fur Bau und Berechnung der Siemens-Martinöfen*, Stahl u Eisen, 45. Jg., 1925, St. 702.

[12] Bansen, Hugo, Rheinhausen-Nrh.: *Einfluss der Vorwärmung von Gas und Luft auf den Gang des Siemens-Martinofens*, Bericht des Stahlwerksausschusses, V. d. E. Nr. 92.

[13] Bericht Nr. 117 des Stahlwerksausschusses V.d.E. vom 13.7.26, Seite 8.

Mitunter setzt man zur Erhöhung der Wärmestrahlung 10 bis 20% Generatorgas zu oder stäubt 5 bis 10 g Teer/1000 Gaskcal in den Gaszug ein.[14] Das Arbeiten mit Mischgas ist dem Betriebe mit reinem Koksofengas vorzuziehen, wenn sich der Ofen bei diesem auch einfach baut. Man kann bei der Gas- und Luftvorwärmung des Mischgases auf Abgastemperaturen von 400° herunter arbeiten, also den Abhitzekessel entbehren. Auch machen sich die Schwankungen des Koksgasheizwertes bei Unterschreitung von 4000 kcal nicht so störend bemerkbar. Die Gichtgasversorgung des Stahlwerkes muss sicher gestellt werden. Notwendigenfalls müssen die Dampfkessel mit Kohle gestocht werden. Bei feststehenden Öfen ist das gebräuchlichste Einsatzgewicht 60 bis 80 t, bei Kippöfen 100 bis 200 t. Die Erkenntnis, dass grössere Badtiefen keinen ungünstigen Einfluss haben, fuhrt zu einer Steigerung des Einsatzgewichtes auf 2 t m^2 Herdfläche bei mittleren Öfen und 3 t m^3 und mehr bei Kippöfen. Die Leistung ist normal 250 kg/m^2 h und überschreitet häufig 300 kg m^2 h.

Der Wärmeverbrauch beträgt bei Mischgasbetrieb 1,25 bis 1,4 . 10^6 kcal t.

Die Steigerung der Stundenleistung ist durch Erhöhung der Einsatzgewichte (10% höheres Gewicht = 5 bis 7% höhere Stundenleistung) und stärkere Gaszufuhr erreicht worden. In diesem Sinne wirkt die Verwendung von Ventilatorluft und Saugzug. Sie gestatten einen gleichbleibenden Ofenbetrieb auch bei älteren Öfen.

Das Umschmelzen von Ferromangan als Zusatz in der Pfanne erfolgt in Flammöfen mit Koksgas bei Lufterhitzung auf 200° bei Leistungen von 150 bis 200 kg/m^2 Herdfläche und Stunde. Das Arbeiten mit geregelter Gas- und Luftzufuhr und die Einstellung nach Messapparaten, wie die Temperaturüberwachung der Kammern, hat mehr zur Hebung der Leistung beigetragen als Sonderbauarten der Köpfe und Kammern.

III.—*Die Walzwerksöfen.*—Wie sich das Gichtgas durch Gas- und Luftvorwärmung oder Beimischung von Koksofengas jedem Wärmzweck betrieblich und wirtschaftlich günstig anpassen lässt, ist bereits gesagt worden. Seine Anwendung seit etwa 20 Jahren führte zunächst zur Entwicklung des Regenerativofens. Die Umschaltfeuerung nach Art des Siemens-Martinofens von Kopf zu Kopf eignete sich wohl für Herdöfen mit satzweiser Beschickung.

[14] Stein, Friedrich: *Zusatz von Karburierungsmitteln bei mit Mischgas beheizten S M. Öfen*, Archiv f. Eisenhüttenwesen, 1. Jg. 1927/28, B.629.

Die Anpassung an den Gegenstrom des Stossofens bereitete aber Schwierigkeiten. Man versuchte sie in mannigfacher Weise zu lösen, etwa durch Ausbildung eines zweiflügeligen Herdes (Abb.8) mit verzögerter Verbrennung so, dass die Haupthitze sich an den mittleren Ziehtüren entwickelt. Siemens wandte die gespaltene Hufeisenflamme an (Abb. 9), indem ein Teilstrom der Rauchgase vom Schweissherd in die Kammern am Ofenkopf zurückgesaugt wird, während der Stossherd im Gegenstrom gegen den Einsatz beheizt wird. Neuerdings kommt man in verschiedener Ausführung

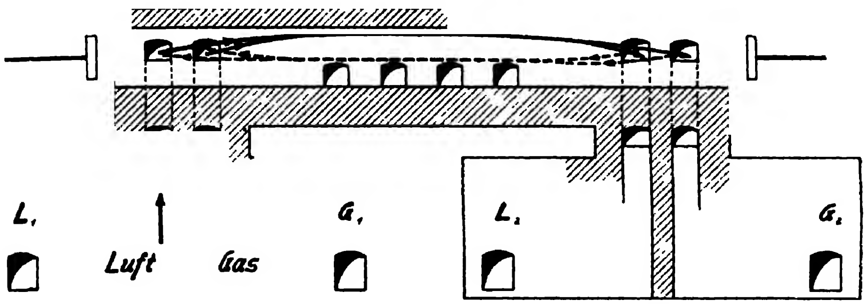

Abb. 8. Regenerativstossofen.

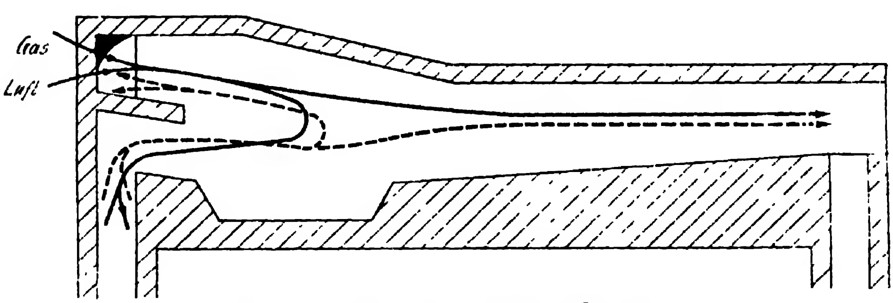

Abb. 9 Ofen mit Hufeisenflamme

auf direkt beheizte Regeneratoren zurück[15] bei denen in einem Verbrennungsraum vor dem Herde aus vorgewärmtem Gas und Luft eine Flamme gebildet wird, die im wesentlichen über den Stossherd H im Gegenstrom geführt wird, von der aber soviel nach dem Wärmebedarf der Luft- bezw. Gaserhitzung direkt in das andere Kammerpaar entsprechend gesaugt wird, dass die Abgastemperatur 300° beträgt (Abb. 10).

Man wärmt dabei auch nur die Luft allein besonders hoch vor und arbeitet mit kaltem Gase oder wärmt nur das Gas im Regenerator durch frische Flammen vor und benutzt die Abhitze des Stossherdes

[15] U.S.P. Nr. 483752 vom 4.10.1892: Jacob T. Wainright: *Method of Working Heat Regeneration*, Fg. 3.

zur Lufterhitzung durch einen Rekuperator. Da zur Erzielung hoher Ofenleistungen und gleichmässiger Durchwärmung die Abgastemperatur des Stossherdes über 600° gehalten werden muss, so ist diese Anordnung wärmewirtschaftlich besonders günstig. Die Verwendung von Koksofengas als Zusatz gestattet eine wesentliche Vereinfachung des Ofenbaues. Kann man mit reicheren Mischungen arbeiten, so genügt der Anbau von Gasbrennern und kalte Luft. Um Wärmestauungen auf dem Schweissherd zu ver meiden, und von vornherein die Blöcke gut durchzuwärmen, verteilt

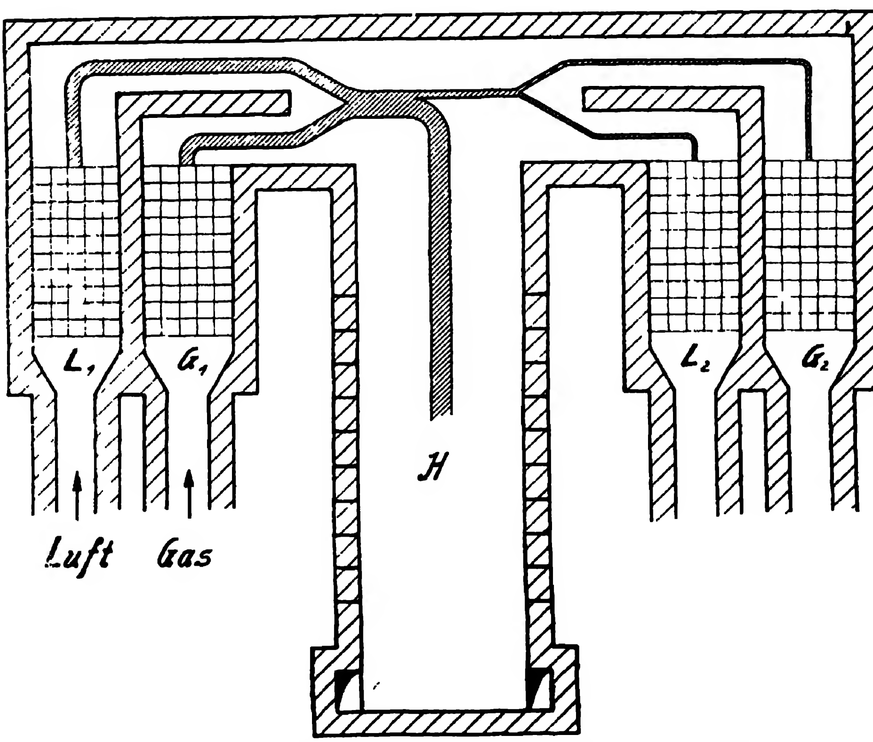

Abb. 10. Stossofen mit regenerativer Kammerbeheizung.

man die Brenner längs des Ofens (Abb. 11). Der Ofen wird zum einfachen Wärmkanal ohne jeden Unterbau und feuerfeste Einbauten. In Europa wohl beachtet, aber kaum ausgeführt, sind umstellbare Plattenerhitzer[16] oder rekuperative Röhrenerhitzer aus feuerbeständigem Stahl, die man wie einen Abhitzekessel neben dem Ofen aufstellen kann und von denen aus Gas und Luft in mit Isoliersteinen ausgemauerten Leitungen zu den Brennern geführt

[16] Waldemar Dyrssen: *Mining and Metallurgy*, Januar 1928, Seite 12/17.

werden, wie es in Abb. 11 angedeutet ist. Mit solchen Mitteln wird es gelingen, den Wärmofen zu einer nie versagenden und höchsten Spitzenleistungen anpassungsfähigen Wärmmaschine zu machen, besonders wenn man auch die Rauchgasabfuhr durch Exhaustoren statt des Kamines lenkbarer macht.

Der Tiefofen, eines der lebenswichtigsten Organe zwischen Stahl- und Walzwerk[17] ist als kohlegefeuerter Ofen schwierig in der Bedienung, ungleichmässig in der Temperatur der nachfolgenden Kammern, teuer in der Unterhaltung. Der Regenerativgasofen lässt sich schwer den schwankenden Anforderungen an die Beheizung und Temperatur bei unregelmässiger Beschickung mit kalten und

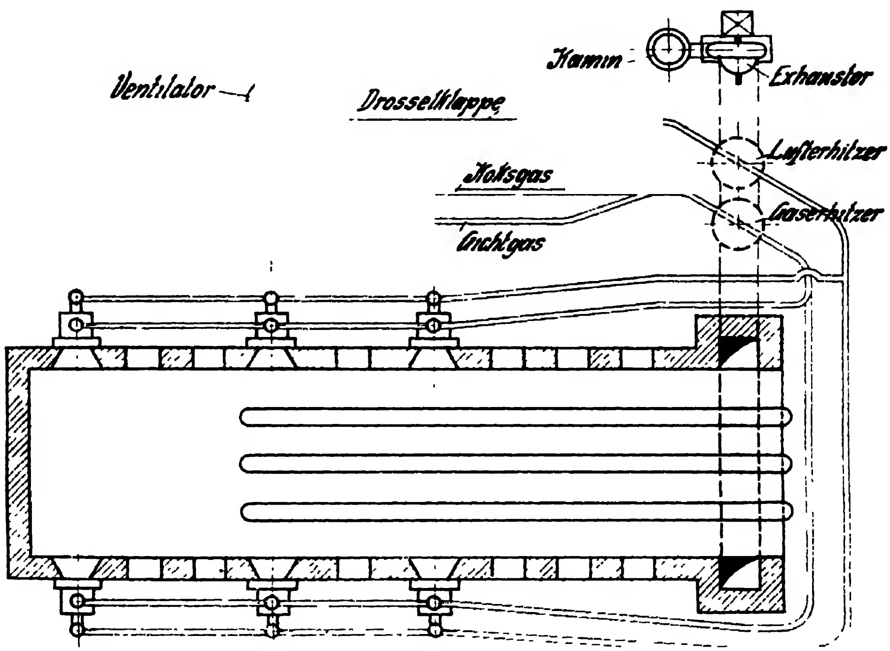

Abb. 11. Stossofen mit Gasbrenner.

warmen Blöcken anpassen und braucht viel Raum; die ungeheizten Ausgleichgruben kühlen unbesetzt und Sonntags aus und senken durch die Wandverluste die mittlere Blocktemperatur um 50°. Ein Fortschritt ist daher die Anwendung der Gruppenbeheizung durch angebaute Gasbrenner mit Mischgas. Man kann die Zellen während des Stillstandes und bei heissem Einsatz durch Gichtgas allein warm halten und durch verstärkten Koksgaszusatz auch

[17] Bansen, Hugo: *Die Zusammenhange des Tiefofens mit der Betriebs- und Wärmewirtschaft,*" Mitteilung der Wärmestelle Nr. 59 vom 22.4.1924.

kalten Einsatz rasch erwärmen. Reines Koksofengas gibt (wenigstens bei Einzelzellen) örtliche Wärmestauungen und ungleichmässige Erwärmung.

Selten ist der Wärmofenbetrieb im Walzwerk ein stetiger Fliessvorgang. Der Einsatz kommt stossweise, bald warm, bald kalt; die Walzenstrasse braucht bei Profilwechsel Blöcke verschiedener Abmessung und schwankende Blockzahl.[18] Diese Verhältnisse erfordern eifrigste Beobachtung. Sie führen zu der Feststellung, dass es an der notwendigen Regelbarkeit und ausreichender Wärmezufuhr für Spitzenleistungen und bei kaltem Einsatz fehlt. Der Ofen wird so lange abgetrieben, bis der Walzenzugmotor, Störung in der Abmessung und Qualität oder ein Bruch Einhalt gebietet. Durch Mischgasdruckbeheizung, Vergrösserung der Abzugsquerschnitte, Saugzug, kann man aller Schwierigkeiten Herr werden. Der Gasverbrauch beträgt bei Regenerativgichtgasöfen und Mischgasfeuerung bei kaltem Einsatz 350 000 bis 450 000 kcal/t je nach Ofenleistung und Ausführung und bei warmem Einsatz 200 000 bis 300 000 kcal/t. Sorgt man nur für verstärkte Gaszu- und -abfuhr, so kann man bei jedem Einsatz Normalleistungen von 250 bis 350 kg/m^2 Herdfläche und Stunde und Spitzenleistungen bis 500 kg/m^2 erzielen.

IV.—*Wärmöfen.*—Aufgaben und Leistungen sind zu mannigfaltig, um Sonderausführungen zu beschreiben. Gichtgas mit und ohne Vorwärmung und Koksgaszusetzung lässt jede Möglichkeit in Wärmezufuhr und Leistung zu. Von dem Irrtum der notwendigen reduzierenden Flamme bei Blechglühöfen kommt man ab, wenn man nur durch genügende Abstrahlung eine ungleichmässige und zu hohe Temperatur vermeidet. Für geringe Arbeitstemperaturen ist vielfach der Gleichstrom für Flamme und Arbeitsstück vorteilhaft. Für Kleinöfen und Wärmmaschinen ist Koksofengas der zweckmässigste Brennstoff. Zur Lufterhitzung genügt vielfach ein Luftmantel um den Kamin, der dünn auszumauern oder in diesem Teil aus feuerbeständigem Stahlblech herzustellen ist.

V.—*Verschiedene Feuerungen.*—Roheisen-Stahlpfannen trocknet man am besten stehend mit einem Druckgasbrenner in einem senkbaren ausgemauerten Deckel, sodass eine Flammengarbe nach unten stösst, und wärmt sie auf 600 bis 800° vor. Konverter bläst man stehend in 3 Stunden durch einen Druckgasbrenner warm,

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[18] A. Koegel. *Einfluss von Angebot und Nachfrage auf Leistung, Grösse und Wärmeverbrauch von Stossöfen,* Ausschuss für Betriebswirtschaft, V.d.E., Nr 13 vom November 1926

den man an Stelle des Bodens einführt. Durch Luftüberschuss verbrennt man den Teer. Zwischenbetrieblich hält man sie in gesenkter Stellung durch die aufsteigende Flamme eines schwenkbaren Mündungsbrenners warm. Sandtrockentrommeln werden mit einem Wirkungsgrade der Wasserverdampfung von 50% im Gleichstrom beheizt, wenn man nicht auf völlige Trocknung arbeitet. Der Brenner muss dem schwankenden Feuchtigkeitsgehalt stets angepasst werden. Weit verbreitet ist die Anwendung des Gichtgases zum Trocknen der Formen in Giessereien. Nur bei Gasüberschuss ist es wirtschaftlich, Spateisenröstöfen, Kalkbrennöfen mit Gichtgas zu beheizen. Diese erfordern einen Koksgaszusatz und müssen für höhere Leistungen mit Gichtverschluss, mechanischer Austragung und Ventilatorwind eingerichtet werden.

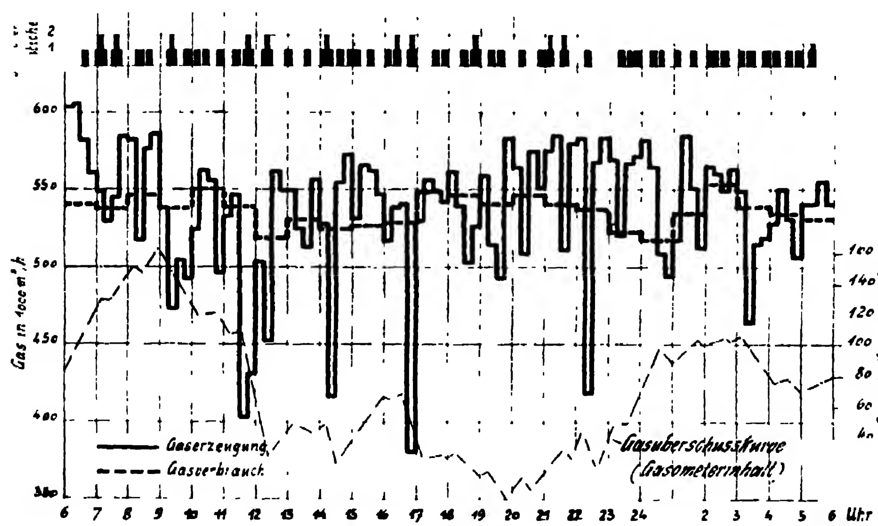


Abb. 12. Hochofengas-Erzeugung und -Verbrauch.

D. Gasangebot und Gasbedarf

Die Betrachtung des Hochofens als Gaserzeuger hat bereits die zeitlich möglichen Schwankungen der Gaserzeugung erkennen lassen. Abb. 12 zeigt ein Tagesdiagramm der Gesamtgaserzeugung von 7 Hochöfen bei Hängestörungen und den Erzeugungsausfall durch das Beidrücken des Windes während der darüber gezeichneten Abstichzeiten. Für längere Zeit streut die Erzeugung in den Grenzen von ± 10%, für kürzere bis 15% und mehr. Demgegenüber steht zunächst organisch ungebunden der Wärmebedarf der verschiedensten Hüttenbetriebe, deren Möglichkeiten, überall Gichtgas zu verwerten, bereits beschrieben sind, gekennzeichnet durch die punktierte Linie. Die Möglichkeiten, in den einzelnen Betrieben

Gichtgas zu verwerten, ergeben für ein Hüttenwerk mit Thomasroheisenerzeugung einen Ausgleich zwischen Gaserzeugung und Bedarf bei den Erzeugungsverhältnissen nach Tafel III, Spalte 1.

TAFEL III.

HOCHOFENGAS-ERZEUGUNG

	m^3
1 t Thomasroheisen	3750

HOCHOFENGAS-VERBRAUCH

Erzeugnis je t Thomasroheisen		Gasverbrauch m^3/t	Gasverbrauch d. Erzeugnisse m^3/t Thomasroheisen		
Bezeichnung		Erzeugnis	je Einzelverarbeitungs Stufe	für die Gesamtverarbeitung	
Thomasroheisen einschl Verarbeitung von Feinerz Gichtstaub u Schlacke ..	1	1448 (1320 + 128)	1448 (1320 + 128)		
Thomasstahl einschl Phosphatmehl	0 88	(235 + 44)	260 (210 + 50)		
Walzgut aus Thomas stahl	0,72	1250	900	2608	
Martinstahl (aus Schrott)	0,44*	400	175		
Walzgut aus Martinstahl	0,36	1250	455	630	
Koks einschl. Nebenerzeugnisse .	0,31		362 (310 + 52)	362	3600
Verfugbar (Verlust) ..					150
Spalte ..	1	2	3	4	

* 0,5 t Martinstahl je t Thomasstahl

Man kann auf 1 t Thomasroheisen 880 kg Thomasstahl und 440 kg Martinstahl erzeugen, also den Rohstahlbedarf zu 67% aus dem Thomasverfahren, zu 33% aus dem Martinverfahren decken, und das für die Beheizung der Martinöfen erforderliche Koksgas selbst herstellen, erhält also 1 t Walzeisen über 1 t Thomasroheisen aus dem Gase von etwa 1 t Koks. Ein Gasverlust von 3 bis 7% der Gaserzeugung ergibt sich bei bester Gaswirtschaft aus den selbstverständlichen Verlusten durch Undichtigkeiten, beim Abblasen, beim Stillsetzen und am Sonntag. Damit und dem Eigenverbrauch des Hochofens für Winderhitzung (20—25%) und Gebläse (9 bis 14%) bleiben 50 bis 55% der Gaserzeugung, also etwa 1800 bis 2000 m^3 Gas/t Roheisen, für andere Zwecke verfügbar. Jede t Martinwalzeisen aus Schrott bindet 1750 m^3 Gichtgas aus dem Überschuss des Gases der Thomasroheisenerzeugung, während bei Walzeisenerzeugung durch den Roheisenerzprozess der Gasbedarf durch das zugehörige Roheisen aufgebracht wird. Betreibt ein Hüttenwerk also neben Thomashochöfen noch Öfen auf Handelsroheisen, so wird es um die Unterbringung des Überschusses in Verfeinerungsbetrieben, in Hilfsbetrieben wie Kalkbrennerei,

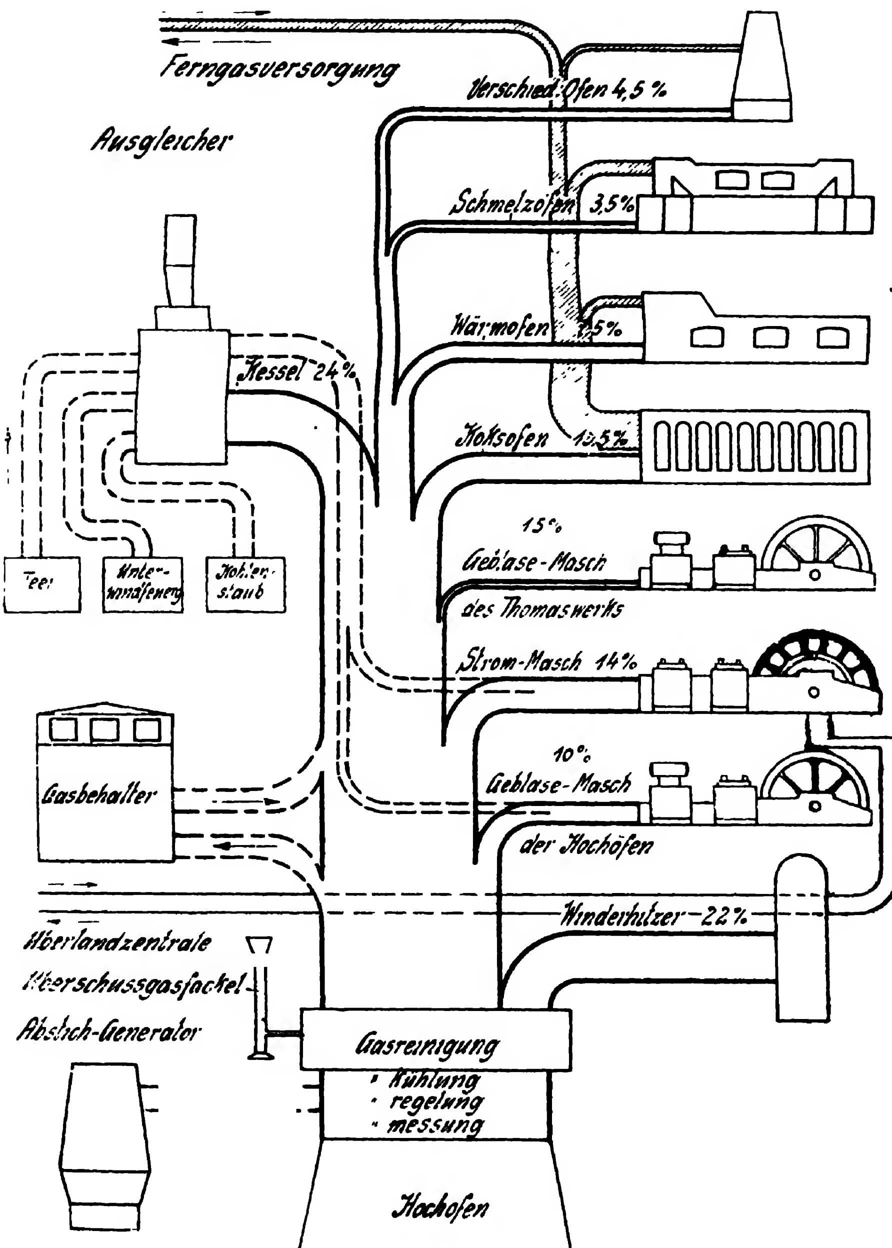


Abb. 13. Hochofengasverteilung.

Zementfabrik, oder Energieabgabe als Strom oder Koksofengas besorgt sein, auch einen Ausgleich in erhöhter Siemens-Martinstahlerzeugung aus fremdem Schrott oder bei niedrigen Schrottpreisen eine Senkung des Koksverbrauches am Hochofen durch starken Schrottsatz suchen. Je knapper das Gas ist, umso stärker wird man elektrisieren, bei hoher Gaserzeugung aber den Dampfbetrieb im Walzwerk beibehalten. Den Fluss des Gasstromes durch die Betriebe zeigt Abb. 13.

Es gibt ebenso viele Möglichkeiten der betrieblichen Gestaltung wie wärmewirtschaftliche Mittel zum Ausgleich. Die leitenden Grundsätze bei einer zielbewussten Gaswirtschaft sollen sein:

Das Gas ist in erster Linie gesichert und geregelt den Betrieben zuzuführen, die 1. ohne ein wirtschaftliches Zusatzmittel in ihrem von der Erzeugung abhängigen Wärmebedarf allein auf Gas angewiesen sind und 2. in denen mit dem Gase höchstwertige Energie oder Wärmegefälle erzeugt werden.

Das sind zu 1. vorhandene Gasmaschinen, zu 2.

(*a*) die Winderhitzer. Der heisse Wind gibt die höchste Arbeitstemperatur im Hochofen und bewirkt eine Koksersparnis.

(*b*) Die Koksöfen. Man erhält je t Koks 1000 kcal Gesamtgichtgasaufwand von geringer Temperaturwertigkeit, etwa 1400 kcal Koksofengas höchster Temperaturwertigkeit, mit dem man weiteres Gichtgas aufwerten kann, um damit

(*c*) Siemens-Martinöfen zu beheizen, teuere Kohle mit den hohen Vergasungskosten und Umsetzungsverlusten zu beseitigen und die Betriebsführung zu vereinfachen, und im gleichen Sinne

(*d*) Wärmöfen zu beheizen. Darüber hinaus ist bei Absatzmöglichkeit

(*e*) die Erzeugung von Koksofengas zur Fernabgabe das wirtschaftlichste Gebiet. Die Schwankungen und der Rest des Gichtgases gehen zu den Kesseln. Für die Stromerzeugung und den Betrieb von Walzenzugmaschinen ist jederzeit am einfachsten und billigsten ohne Störung der Betriebseinheitlichkeit, Kohle einzusetzen.

Der Ofenarbeiter soll in erster Linie metallurgischer Helfer, also Schmelzer, Wärmer, aber nicht Heizer, sein.

Diese Grundsätze werden in Abb. 13 zur Anschauung gebracht. Das Gas wird in der Reinigung vom Hochofen übernommen. Durch Stauregelung ist in der Rohgasleitung ein gleichmässiger Druck zu halten. Sie erfolgt bei Überschuss durch Abblasen aus einer Fackel mit Druckgaszündbrennern. Die Wäsche ist die gegebene Vermittlungsstelle des Gasdienstes. In ihr wird die ganze Gaserzeugung erfasst

und gemessen. Die Übersicht wird erhöht durch Anzeigen über die Windmenge der Hochöfen (1,35 = m^3 Gas/m^3 Wind), das Stillsetzen und Anfahren derselben und die Belastung der Betriebe. Eine direkte telephonische Verbindung mit Hochofen und Gasverbrauchern macht die Anlage vollkommen. Die Winderhitzer schalten als Wärmeausgleicher für den Gasbetrieb bei hochbelasteten Öfen völlig aus, je mehr sie mit grosser Heizfläche und kleinstem Speichergewicht für rasche Umstellung gebaut werden. Die weitere Grundlast geben die Gebläsemaschinen und die Strommaschinen, wenigstens so weit sie mit Gas betrieben werden. Bei Dampfbetrieb reihen sie sich durch den Kessel besser in den Ausgleichbetrieb ein. Siemens-Martinöfen und Wärmöfen entnehmen Gichtgas nach Bedarf, wobei die Aufrechterhaltung eines genügenden Vordruckes selbstverständlich ist, um Erzeugungsausfälle zu decken.

Die Kessel stellen zweckmässig den einzigen Ausgleich dar, weshalb bei rein elektr. Walzwerksantrieb zum wenigsten ein gemischter Betrieb von Gasmaschinen u. Dampfturbinen in der elektr. Zentrale notwendig ist. Den Ausgleich der häufiger eintretenden Unterbelieferung an Gas gleicht man am einfachsten mit Teer oder Teerölfeuerung aus, bei der die höheren Brennstoffkosten gegenüber den geringen Anlagekosten und der steten Betriebsbereitschaft zurücktreten. Längerer Gasmangel wird durch Zusatzkohlenfeuerung mit Unterwindrosten oder Kohlenstaub ausgeglichen. Dampfspeicher finden auf Hüttenwerken wenig Platz, weil keine Verwendung für Mitteldruckdampf da ist, ebensowenig Speisewasserspeicher, weil sie nur für längere Zeit in mässigen Grenzen aber nicht für grosse Spitzenentnahmen speichern können.

Man kann den Hochofenbetrieb bis zu einem gewissen Grade bei längerem Ausfall eines Ofens durch verstärktes Blasen der anderen ausgleichen, wenn der Ofengang es zulässt und höherer Druck zur Verfügung steht. Man soll jedoch alles unterlassen, was sein Gleichgewicht stört. Er kann sich auch durch höheren Kokssatz bei geringerer Windtemperatur dem Gasbedarf anpassen, sofern er die grössere Windmenge aufnehmen kann. Die Wirtschaftlichkeit ist trotz des höheren Brennstoffpreises durch den hohen Wirkungsgrad der reinen Vergasung zu Kohlenoxyd bei niedriger Abgastemperatur und die Ersparnis verteuernder Ausgleichseinrichtungen gegeben. Die Halberger Versuche[19] lassen diese Zusatzvergasung auch durch Einblasen von Kohlenstaub ohne metallurgische Einwirkung in einem gut durchsetzenden Ofen in oder

[19] Bertram, E.: *Das Einblasen von Schmelz- und Brennstoffen in die Gestellzone*, Archiv für Eisenhüttenwesen 1927/28, A 19.

über den Formen als durchaus möglich erscheinen. Ein weiteres Mittel zum Ausgleich im Gasnetz zur Vereinheitlichung des Gasbetriebes ist der Abstichgenerator. Er lässt sich automatisch durch Regelung der Windzufuhr plötzlich stark überlasten und verträgt längere Stillstände. Empfehlenswert ist zur Hebung der Wirtschaftlichkeit und Senkung der Gichttemperatur ein leichter Erzsatz und das Arbeiten mit heissem Wind zur Erleichterung der Schlackenarbeit namentlich bei schwachem Betriebe. Man kann anstandslos darin nicht backende Kohlen wie auch brennstoffhaltige Aschen vergasen, wenn man nur den Abrieb auch bei Koks fern hält. Er wird am besten an die Rohgasleitung angeschlossen. Die Beschikkung muss für geringsten Leutebedarf eingerichtet sein, damit bei schwachem Zusatzbetriebe die Unkosten gering bleiben.

Die hohen Anlagekosten eines Gasometers von M 12 000.-bis 6000.-/1000 m^3 Inhalt bei Grössen von 20 000 bis 200 000 m^3 erfordern einen 850 bis 400-fachen Gasdurchsatz im Jahr, um den Kapitaldienst aufzubringen. Er wird sich also nur in den seltenen Fällen bezahlt machen, wo ähnlich Abb. 11 sich laufend Gasbedarf und -verbrauch so überschneiden, dass das Gas restlos von Berg zu Tal übertragen werden kann. Erst wenn man durch einen 100 000 m^3 Scheibengasbehälter im Jahre M 110 000.- = 5000 bis 7000 t Zusatzbrennstoff am Kessel sparen kann, ist seine Anlage zu befürworten. Anders ist es bei Koksofengas mit einem 4 mal grösseren Kohlenheizwertpreis und einem 7 bis 10 mal höheren Gebrauchswert für Hüttenwerke.

Wenn es auch üblich ist der einfachen Verrechnung wegen einen Durchschnittsgaspreis auf Kohlenheizwertgrundlage anzusetzen, so kommt man bei genauen Wirtschaftlichkeitserwägungen nie über Sonderbewertungen hinweg. Das Gichtgas, wie das Koksofengas, haben keinen Preis, weil sie nicht um ihrer selbst willen erzeugt werden, sondern nur einen Gebrauchswert, der sich von Fall zu Fall aus dem geldlichen Vorteil in Stoff-, Anlage- und Betriebskosten bei seiner Anwendung errechnet.

Der niedrigste Gebrauchswert ist daher der am Kessel, der höchste der an der Kokerei. Man kann bei der Wahl, ob man eine neue Koksofenanlage auf die Hütte oder Zeche setzen soll, auf der Hütte Gichtgas ohne Sonderanlagekosten für seine Verwertung unterbringen und für das gleiche Anlagekapital die doppelte Koksgasmenge als bei Starkgasbeheizung frei machen. Man hat dafür nur als Mehrbelastung die Überfracht für Kokskohle gegen Koks, also für 0,4 t, zu tragen. Dadurch stellt sich der Koks auf der Hütte gegenüber dem Lieferkoks um 20 bis 25% billiger. Selbst wenn

man aber das Gichtgas durch Kohlenstaubfeuerung an den Kesseln ersetzen muss, das Gichtgas also mit diesem Kohlenwert einzusetzen ist, bleibt eine Ersparnis von 10 bis 15%.

Der wirtschaftlichste Weg für die Koksgaserzeugung geht also über die Hüttenkokerei. Es ist wirtschaftlicher, Strom über Kohle zu machen, oder bei günstigen Bedingungen sogar zum wenigsten die Spitzendeckung von einer Überlandzentrale zu beziehen.

Erst wenn man keine andere Möglichkeit der Gichtgasüberschussverwendung hat, wird man sich entschliessen, Kapital festzulegen um Strom im Überschuss zur Abgabe über Land zu erzeugen. Im allgemeinen wird ein solcher Betrieb nur mit bereits vorhandenen reichlich bemessenen Anlagen möglich sein.

Die Gichtgaswirtschaft mit ihren vielen Verquickungen mit den Hüttenbetrieben hat eine Fülle von technischen Möglichkeiten, aber für jeden Fall eine einzige wirtschaftlich günstige Lösung. Nicht derjenige Wärmewirtschaftler wird am erfolgreichsten sein, der eine wärmetechnische Einzelaufgabe physikalisch und chemisch am besten löst, sondern der die gebotene Möglichkeit wirtschaftlich am günstigsten ausnutzt. Je mehr er die technischen Grundlagen beherrscht, umso leichter wird ihm die Wahl der richtigen Mittel sein.

THE USE OF GAS IN GERMAN IRON AND STEEL WORKS

DR. BANSEN

(*English Translation*)

At the commencement of the War, German iron and steel works were faced with the problem of supplying the largest possible quantity of steel with an insufficient supply of fuel. Endeavours to utilise blast furnace gas as efficiently as possible led from fundamental considerations regarding the production and transmission of heat to investigation of their complicated relations with metallurgical and manufacturing problems. Heat economy thus became the guiding principle of the manufacturing methods in general. The question of heat economy is no longer considered in terms of heat units alone, but in tons and marks. It still considers, however, economies in fuel, as the fuel costs amount to 20 to 30 per cent. of the total production cost of the rolled iron, whilst the value of the blast furnace gas represents one-sixth to one-seventh of the production costs of pig-iron, and the maintenance of the increased output is only ensured by rational recovery and treatment of the gas. Detailed organisation of the inter-relations of all departments with reference to the gas is the main condition for the uninterrupted operation of the manufacturing processes of a modern steel and iron works.

(a) Blast Furnace Gas

1. *Production*.—The purpose of a blast furnace is the separation of the ore from the accompanying gangue and the fixation of the oxygen contained in the ore. As most blast furnace burdens contain 20 to 30 per cent. of their iron in the form of FeO, their oxygen contents differ but slightly from 280 cu. metres of oxygen per ton of pig iron recovered. This oxygen can be removed (1) by carbon monoxide. If this gas is present from any source (*i.e.*, in the hearth) and if the necessary reaction temperature is attained (through the surplus heat of the hearth reactions), then the further addition of neither carbon nor heat is necessary (indirect reduction)

The oxygen in the ore may also be removed (2) by carbon with formation of carbon monoxide. The two stages of oxidation FeO and Fe_2O_3, require for this purpose 214 and 320 Kg. of carbon respectively per ton of iron, and the additional heat requirements for the reductions of these two oxides are 659,000 and 1,016,000 Kg. cals. per ton of iron respectively, as the heat liberated by the combustion of the carbon to carbon monoxide by the oxygen contained in the ore is insufficient (direct reduction).

The third possibility is that one-half of the oxygen in the ore is reduced directly, and that the carbon monoxide which is thus formed reduces the other half indirectly. The total effect is, then, that the oxygen in the ore is converted by carbon into carbon dioxide One-half of the oxygen of the ore then requires neither additional carbon nor additional heat, and only one-half of the carbon and of the heat are necessary which are required by direct reduction (50 per cent. indirect reduction).

This case, which occurs, broadly speaking, with many furnace charges, is called "50 per cent. indirect reduction." The quantities of carbon and of heat theoretically required for this reaction, including the reduction of the oxides of silicon, manganese and phosphorus, are 160 Kg of carbon per ton of pig iron from the ore, compared with about 800 Kg. of carbon (1,000 Kg. of coke), which is necessary in practice in order to supply the required heat. Five per cent. of this coke are recovered as carbon in the pig iron, 20 per cent. are required for the reduction of the ore, and the remaining 75 per cent. are used for heating the furnace by combustion in front of the tuyères. At the high temperature which is there present it burns to carbon monoxide only, supplying only 2,412 Kg. cals. per Kg. of carbon, the additional requirements being 506 Kg. cals., for reduction[1], 560 Kg. cals. for the sensible heat of the iron and the slag, 290 Kg. cals. for driving off the carbon dioxide and water, 225 Kg. cals. for cooling losses and 397 Kg. cals. for the sensible heat in the evolved gases. If carbon were burned in cold moist air, the temperature attained would be 1,315°C. only. This temperature is lower than that of the tapped iron and of the slag, and is, moreover, so low that the direct reduction would only occur very slowly. This fact indicates the importance of the passage of the coke and the charge in counter-current to the evolved gas, which not only effects the essential loosening of the column of the charge, which is

[1] All these figures, in this case and in the rest of the article, refer to 1 Kg. pig iron of a Blast Furnace producing basic pig iron with 50 per cent. indirect reduction, 600°C. blast temperature, 300°C. flue gas temperature, 970 Kg. of coke containing 82 per cent. of carbon per ton of pig iron from ore.

necessary in order that the ore may be penetrated by the gas, but also effects the pre-heating of the coke to the temperature of the hearth. If the coke is pre-heated by 100°C., this increases the available heat from its combustion by 40 to 50 Kg. cals., and the temperature of combustion by 25°C., so that, by pre-heating the coke to the hearth temperature, 600 to 700 Kg. cals. per Kg. of carbon are available in addition to the heat of combustion. Thus the regenerative system is as fundamentally important in a blast furnace

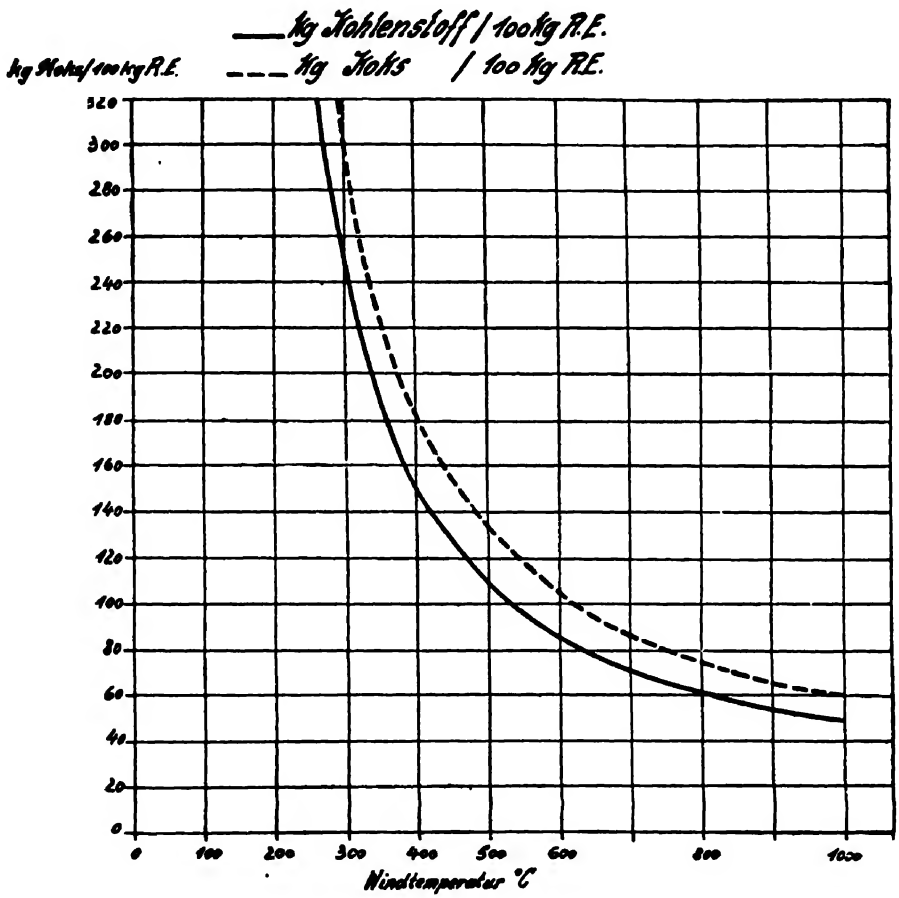


Fig. 1.

VARIATIONS OF COKE CONSUMPTION WITH TEMPERATURE OF BLAST

Kohlenstoff	= Carbon.	RE	= Pig iron.
Koks	= Coke.	Windtemperatur	= Temperature of blast.

as in an open hearth steel furnace. It is only by pre-heating the fuel by waste heat that an effective heat potential is available for the operations in the hearth. The blast furnace process can also be carried out with a cold blast, although with greater coke requirements. This essential consideration also explains in a simple manner the extraordinary fall in the coke requirements if the air is pre-heated. The relationships are shown in Fig. 1. Per 100°C. increase

in the temperature of the blast, one obtains a heat increase of 140 Kg. cals., and an increase of the theoretical temperature of combustion of 70°C.; consequently, the consumption of coke increases rapidly with falling blast temperature. With alteration in the conditions of the reduction, this increase may, and in practice does, undergo variations in both directions. 80 per cent. of the coke is burned by the blast in front of the tuyères, and a further 10 per cent. is used in the hearth and the lower bosh for direct reduction. Blast furnace coke must be as resistant as possible to combustion, and must also resist pressure, in order that it may reach the hearth in unchanged form. The quantitative production of blast furnace gas from its constituents occurs, as shown in Table I. The varying proportions of re-

TABLE I.

COMPOSITION OF BLAST FURNACE GAS

	Cu. metres of Gas per Kg. of Basic Pig Iron from:										Total of constituents of gas	
	Charge		Decomposition of water vapour (Atmospheric moisture)		Decomposition of coke		Oxidation of Carbon. 50 per cent. indirect Reduction		Gasification of Coke by blast			
	m^3	per cent.	m^3	per cent.	m^3	per cent.	m^3	per cent.	m^3	per cent.	m^3	per cent.
CO_2	0·0433	100					0·3	100			0·3433	9·2
CO			0·035	50					1·126	34·2	1·1610	31·2
H_2			0·035	50	0·035	78					0·0700	1·9
N_2					0·016	22			2·13	65·8	2·1460	57·7
Total	0·0433	100	0·070	100	0·051	100	0·3	100	3·256	100·0	3·7203	100·0
Proportion of total gas		1·2		1·9		1·4		8·0		87·5		

ducing gas and oxidised gas are determined by gas analysis. Fig. 2 shows the wide alterations in composition for from 100 to 0 per cent. direct reduction and 60 to 150 Kg. of coke per 100 Kg. of pig iron. These alterations are characterised by an increase in the nitrogen and carbon dioxide, and a fall in the carbon monoxide contents. In practice, the activities of the blast furnace gas producer are limited to the interval from 70 to 30 per cent. of direct reduction, and coke charges of 80 to 120 Kg. per 100 Kg. of pig iron. Within this field the contents of carbon dioxide vary from (5·0 to 8·2 per cent.) to (8·9 to 13 per cent.), and of carbon monoxide from (35 to 36 per cent.) to (25 to 28 per cent.), as is shown hourly and daily in practice. With a coke charge of 80 Kg. per 100 Kg. of pig iron, and an indirect reduction of about 70 per cent., one obtains a proportion of CO to CO_2 of 2 : 1, which is the figure mentioned by Bell as the limiting obtainable value. More favourable values have probably seldom been observed.

The considerable fluctuations of the composition of the gas during actual operations are shown in Fig. 3. They are caused by the fluctuations in the supply of carbon, by the downward pressure of the charge, which varies by ± 10 per cent., by the variations in the carbon contents of the coke, which are of the same order, and by the alterations in the reduction relationships due to changes in the temperature at the boundary of indirect and direct reduction and to variations in the degree of contact with the gas.

Fig. 4 shows the influence of varying degrees of reduction on the blast furnace process under the conditions given in footnote 1. In the average case of 50 per cent. indirect reduction, the coke requirements are 97 Kg. per 100 Kg. of pig iron from the ore corresponding to the usual operating conditions. With

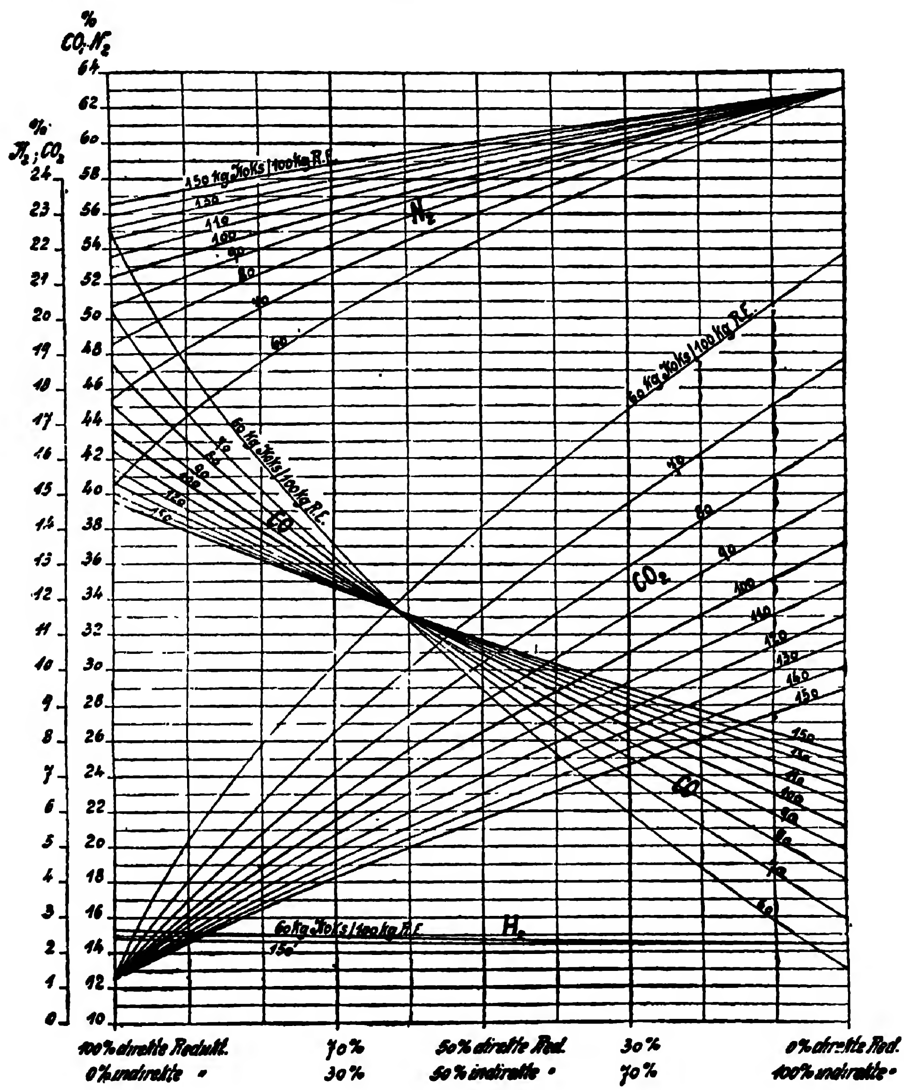


Fig. 2.

VARIATION OF COMPOSITION OF BLAST FURNACE GAS WITH PROPORTION OF COKE AND WITH DEGREE OF REDUCTION

Koks = Coke.
RE = Pig iron.

exclusively indirect reduction 53·6 Kg. only would be required, whereas under the most favourable practical conditions of 70 per cent. indirect reduction, 80 Kg. are required, which amount would be increased to 145 Kg. by exclusively direct reduction. When the indirect reduction is decreased by 10 per

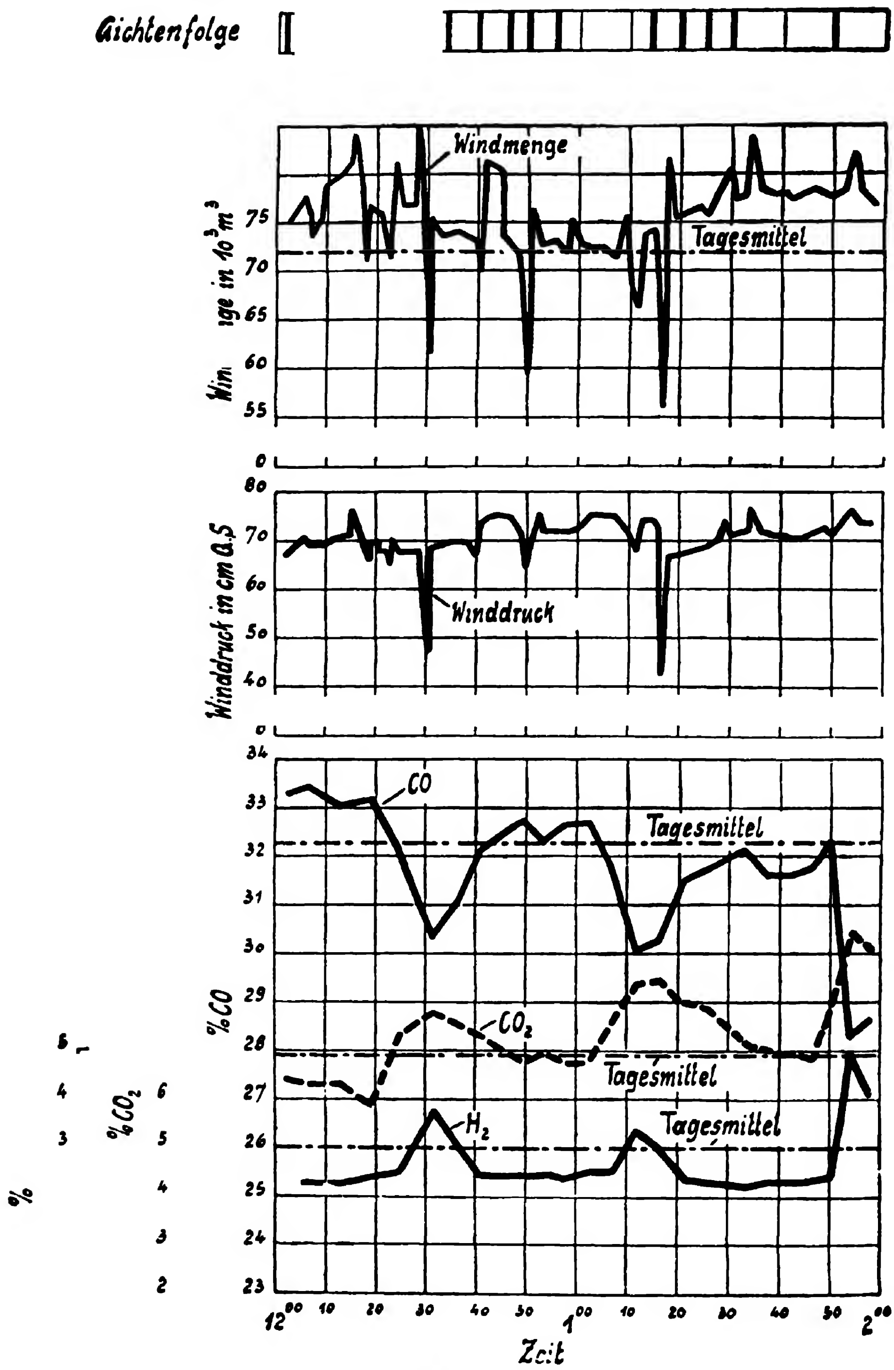


Fig. 3.

FUNDAMENTAL DATA OF CONTINUOUS WORKS CONTROL

Gichtenfolge = Sequence of charges.
Windmenge = Amount of blast.
Tagesmittel = Daily average.
Winddruck = Pressure of blast.
Zeit = Time.

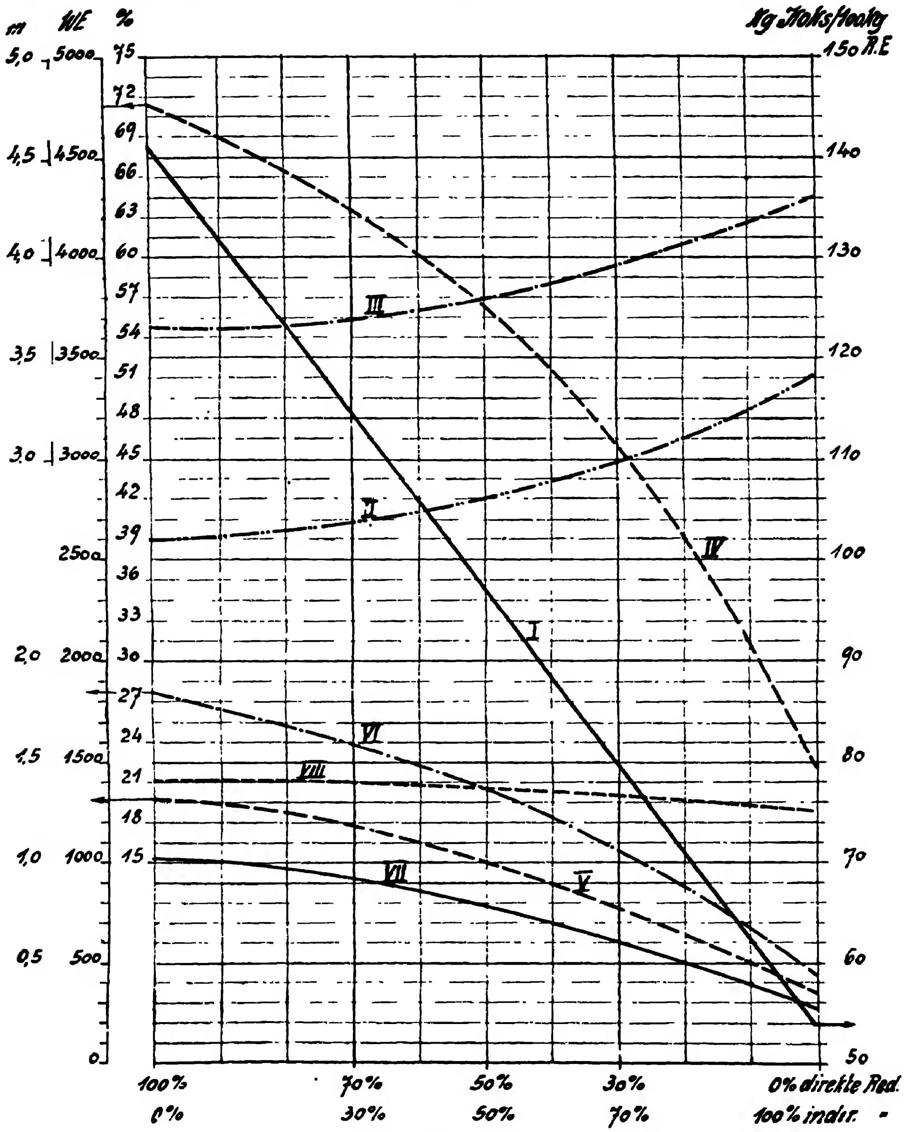


Fig. 4.

VARIATION OF COKE CONSUMPTION AND GAS PRODUCTION WITH THE DEGREE OF REDUCTION

(Basic pig iron, 600°C. blast temperature, 300°C. flue gas temperature, 70 Kg slag per 100 Kg. pig iron).

I. = Kg. of coke per 100 Kg. pig iron.
II. = Cu. metres blast per Kg. coke.
III. = Cu metres gas per Kg. coke.
IV. = Calorific value of gas in heat units per Kg. coke.
Calorific value of gas in percentages of the calorific value of the coke. } 2 scales
V. = Calorific value of blast furnace gas.
VI. = Calorific value of gas in heat units per cu. metre of blast.
VII. = Air requirements for combustion in cu. metres per cu. metre of blast furnace gas.
VIII. = Cu metres of gas per cu. metre of blast.
WE = Heat units.
Koks = Coke.

cent. the coke requirements are increased by 90 Kg. per ton. If the temperature of the escaping gases were altered by ± 100°C., the coke requirements would be altered by 40 to 60 Kg. per ton of pig iron; whilst if the blast temperature were altered by ± 100°C., the coke requirements would be altered by 35 to 50 Kg. per ton of pig iron. These figures show the considerable effects of small changes on the working of the furnace, and also show the necessity of maintaining constant all working conditions which can in any way be controlled. When considering the blast furnace as a gas producer, one should note the changes due to varying conditions, which are as follows:—

	Curve No.	30 per cent. indirect reduction.	50 per cent. indirect reduction.	70 per cent. indirect reduction.
Calorific value in Kg. cals. per cu. metre	V.	1180	1000	780
Calorific value of the gas as a percentage of that of the coke	IV.	64	56	46
Calorific value of the gas in Kg. cals. per cu. metre of blast	VI.	1600	1360	1060
Cu. metres of blast per Kg. of coke	II.	2·68	2·8	2·98
Cu. metres of gas per cu. metre of blast	VIII.	1·39	1·36	1·32

One notes variations, in both directions, of ± 5 to 20 per cent. The blast furnace is by no means an ideal gas producer if one considers that the throughput of air and the consequent production of gas, with insufficient forcing by the blowers, is strongly dependent on the constantly varying resistance, and may vary by ± 15 per cent. from the average. This fact is illustrated by Fig. 5, which clearly shows how sudden alterations in the air supply change the proportions of gas to blast beyond the limits of 7 per cent. Gas analysis[1] is an excellent means for observing the operation of the blast furnace; the changes in the proportions of nitrogen and of carbon dioxide, in particular, are of the greatest value. In conjunction with the quantity of air, these proportions enable the course of the more important phenomena to be followed with the help of Figs. 4 and 5. With the help of careful observations many improvements can be made which assist the uniform operation of the blast furnace both as a gas producer and as a producer of metal.

II. *Purification.*—Dependent upon the degree of sub-division of the ore, the friability of the coke and the gas velocity at the throat of the furnace, 2 to 6 per cent., or even 10 per cent., of the charge is converted into dust, corresponding to 12 to 60 gm. per cu. metre of gas.

The steam contents of the gas amounting to 30 to 60 gm. per cu. metre, and which may even attain 100 gm. and more, if the burden is very moist, leads to condensation and to conversion of the dust into encrustations in the mains and valves. By forming such adherent coatings the dust hampers

[1] Hugo Bansen, *Beurteilung der Stoff- und Wärmebilanz des Hochofens nach der Gichtgasanalyse und der Windmenge* (Control of the chemical and heat balance of the blast furnace by gas analysis and determination of the amount of the air supply); Archiv für Eisenhüttenwesen, Vol. 1, 1927/28, A.245.

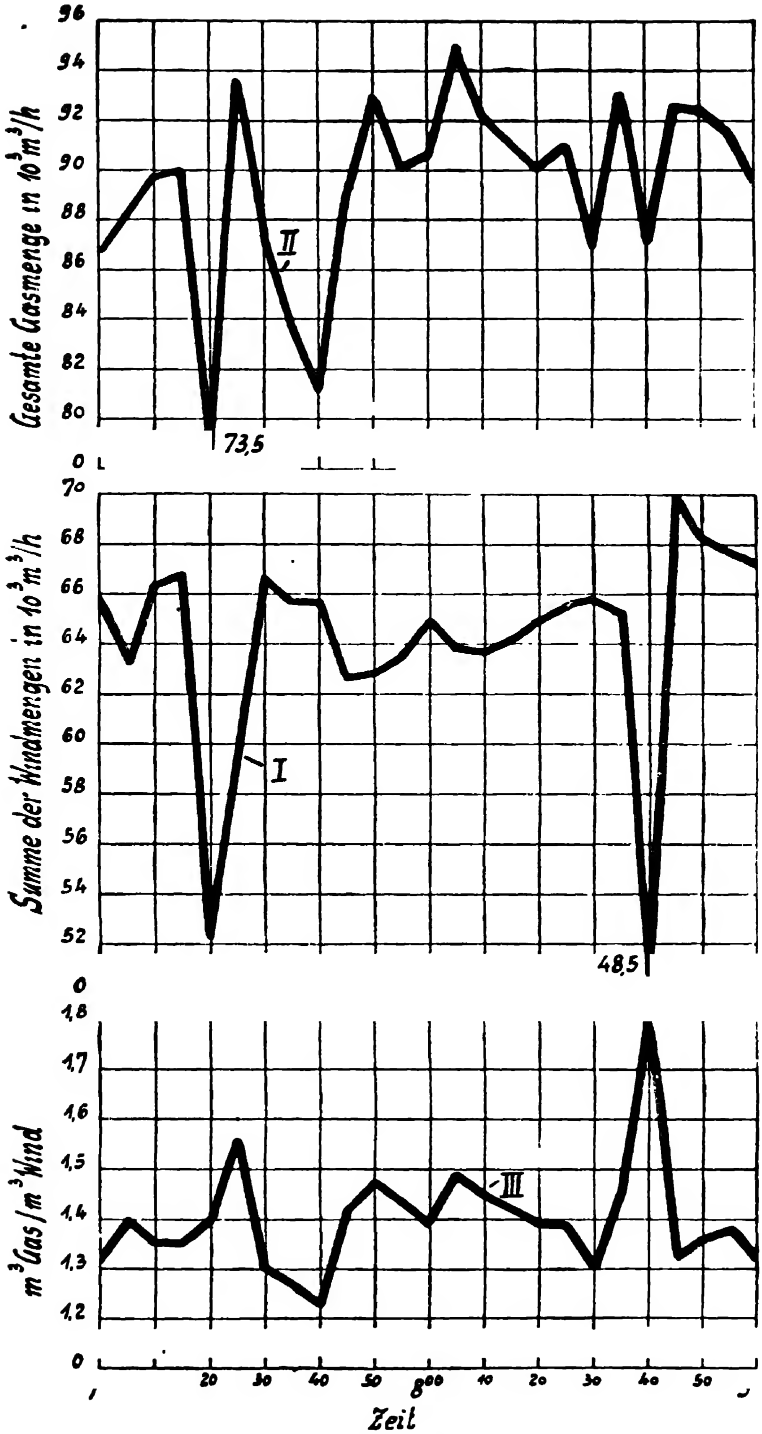


Fig. 5.

VARIATIONS OF PROPORTIONS OF GAS PRODUCTION TO BLAST

Gesamte Gasmenge	=	Total quantity of gas.
Summe der Windmengen	=	Total quantities of blast in 1000 cu. m. per hr.
m^3 Gas/m^3 Wind	=	Cu. metres of gas per cu. metre of blast.
Zeit	=	Time.

heat transmission, and may reduce the efficiency by 10 to 20 per cent. The gas must, therefore, be purified and cooled.

The removal of the coarser dust is effected in vertical dust-catchers of 5 to 10 metres diameter and 10 to 20 metres high, at a velocity which should be less than 0·5 metres per second; the quantity of dust is thus reduced to 5 to 15 gm. per cu. metre. Before washing, the gas is first pre-cooled from 150°-250°C. to 30°-40°C., and simultaneously further cleaned until it contains 0·5 to 1·5 gm. per cu. metre, by means of washing towers containing wooden hurdles and spray nozzles in which the ascending gas meets a descending spray of liquid. The through-put is 100 to 150 cu. metres of gas per cu. metre of cooling space, and the requirements of water are 2 to 3 cu. metres per 1,000 cu metres, whilst the pressure drop is 50 mm. of water column. The final cleaning follows in Theisen washers, in which the power requirements are 5 to 6 kWh. per 1,000 cu metres, and in which the gases are cleaned to 0·01 gm. of dust and less per cu. metre, the continuous through-put being 85,000 cu metres per hour with an emergency through-put of 100,000 cu. metres per hour, whilst the water requirements are 0·7 cu. metres per 1,000 cu. metres of gas, the efficiency is more than 90 per cent.

The dry cleaning of the gas by the Hallberg-Beth process is carried out without preliminary washers by filtering bags, which reduce the dust contents from 10 gm. to 0·004 gm per cu. metre, a small cooling column is, however, required, in which the temperature is reduced to about 100 C. by a water spray, and in which about 5 gm. per cu. metre of dust are precipitated. The nominal through-put of an installation for 36,000 cu. metres per hour is achieved for short intervals, but the actual through-put of the plant is only 60 to 75 per cent. of this figure in consequence of stoppages for repairs and cleaning and also in consequence of obstruction of the filters. The internal power requirements are small, being 0·25 to 0·5 kWh. per 1,000 cu. metres, and the water requirements for temperature regulation are also small, being 0·18 cu. metres per 1,000 cu. metres of gas; in consequence, however, of the considerable pressure drop of 200 mm. of water column, an increased pressure of 200 mm is required for conveying the gas, entailing a power consumption of 2·2 to 3·2 kWh. per 1,000 cu. metres, and the subsequent cooling of the gas at an exit temperature of 70°C. to 20°C requires 2·5 to 3·0 cu metres of water per 1,000 cu. metres of gas in order to obtain a really dry gas such as may be used without difficulty for gas supply and for firing.

As compared with a filtration plant of the same through-put, with subsequent cooling and the necessary pressure increase, wet washing requires up to 150 per cent. more current, and also necessitates a settling tank It require , however, less supervision and smaller repairs, namely, 0·15 marks per 1,000 cu. metres as against 0·21 marks per 1,000 cu. metres; it also requires only half the capitalisation cost for the same nominal through-put, namely, 4,000 marks per 1,000 cu. metres compared with 8,000 marks per 1,000 cu. metres, and only one-third of the capitalisation costs for the same actual operative efficiency. Similar considerations apply to the space requirements It only requires one-twentieth of the area Electrical gas purification requires very little current for the actual process. For completing the process it requires, however, the same arrangements as ordinary dry purification The efficiency falls considerably with increased degree of purification Where water supplies are limited, filtration and electrical gas purification are more advantageous

if one is willing to make the best of uncooled gas. The conservation of the sensible heat of the gas is of no serious advantage. It is lost if the main is of any length, and merely increases the pressure drop and the difficulty of measuring the gas, and causes separation of water when the temperature falls below the dew-point.

III. *Distribution.*—As the pressure drop in gas mains, apart from friction losses, is mainly due to impact caused by changes in direction and in diameter, sharp bends and sudden changes in diameter should be avoided[3]. The mains should be as straight as possible. The velocity (at 0°C. and 760 mm.), should therefore not exceed 8 metres per second through bends; in straight, smooth mains of 200 to 300 mm. diameter it may be 10 metres per second, and in mains of 1,000 mm. diameter up to 20 metres per second, but it should be noted that riveted seams and incrustations increase the resistance two or three fold, and that with hot gases the resistance increases in the ratio $(1+\alpha t)$. Double gate valves with ample air clearance and corrugated expansion joints are preferable to mitre valves. A steady pressure cannot be maintained in long mains with varying withdrawal of gas at the individual points of supply in consequence of the pressure drop, even if a gas-holder is interposed. A uniform pressure is, however, an essential condition for maintenance of the gas supply for an existing furnace or engine. Therefore, it is necessary to include pressure regulators in the principal branch lines and in front of the more important points of consumption. If the gas pressure in front of the branch supply is insufficient to ensure uniform supply with increased demand, it is better to interpose at that point an intermediate fan in order to increase the pressure by 100 to 200 mm., rather than to increase the main supply pressure. As a regulator, a throttle valve carried on external ball bearings should be used. Control is best carried out by bell regulators of 1 sq. metre area = 1 Kg. readjustment pressure per 1 mm. water column, and pipe connections of 150 mm. bore to render rapid equalisation of pressure possible, or by electrical or hydraulic control.

In the case of furnaces which have often to be adjusted in accordance with the demands, it is advisable to interpose a regulator for the air supply in accordance with the gas supply, more particularly in cases where several burners are to be operated simultaneously or where two different gases are in use.

IV. *Firing.*—Whilst, for example, with a gas pressure varying between 50 and 100 mm., the quantity of air must be adjusted to the largest quantity of gas, that is, for an average excess of air of 25 to 30 per cent., one may work with 0 to 10 per cent. excess of air if the gas pressure is constant. With a 10 per cent. excess of air the contents of carbon dioxide fall by about 1 per cent., the temperature of combustion by 50°C., the actual furnace temperature by 30° to 40°C., and the useful work of the furnace by 3 to 10 per cent.; on the other hand, the quantity of flue gas and consequent heat loss with the flue gases increase by 5 per cent. As, however, the temperature of the flue gases also increases by 30° to 50°C., the heat loss with the flue gas is further increased

[3] Hugo Bansen, Rheinhausen-Nrh.: *Berechnung des Druckabfalls in Gasleitungen und gemauerten Kanälen* (Calculation of the pressure drop in gas mains and masonry ducts); Archiv für Eisenhüttenwesen, Vol. 1, 1927/28, p. 187.

by 10 per cent. and more. The more intimately the gas and air are mixed the more they are pre-heated, and the more the combustion zone is shortened by interpenetrating the gas and air streams by means of vortex burners, the more complete will be the combustion, and consequently, the smaller will be the combustion zone and the higher the temperatures of the flame and of the furnace. If, for example, as in Cowper stoves or old boiler burners, gas and air are injected in parallel in wide and rectilinear streams, a combustion zone of 10 to 20 metres is required for the complete combustion of the carbon monoxide, and 150,000 to 300,000 Kg. cals. are developed per cu. metre of the combustion chamber; if the gas and air channels are more sub-divided, as in furnace heads, the heat output rises to 1,000,000 Kg. cals. per cu. metre per hour in a combustion zone 3 to 5 metres long. With vortex burners, however, 15,000,000 Kg. cals. per cu. metre per hour are obtained when 40 to 50 per cent. of the combustion is completed at the burner exit and complete combustion occurs within a length of 1 metre. The temperature factor[4] is increased by 10 to 15 per cent., the flame temperature by 150° to 200°C., and the furnace temperature by 100° to 150°C., so that working temperatures of 1,200° to 1,300°C. can be attained even with cold blast furnace gas.

If the air or the gas is pre-heated when firing with blast furnace gas, per 100°C. of pre-heating there is an additional heat supply of about 30 Kg. cals. per cu. metre of gas and an increase of the temperature of combustion of about 40°C. The flue gas temperature falls by 60° to 70° per 100°C. pre-heating of the gas or the air according to the efficiency of the heat exchanger. If, for example, the waste gases expelled at 1,000°C. from a furnace are used for pre-heating the gas and air supply by about 280°C., the temperature fall of 720°C. suffices to heat both the gas and air to 500° to 600°C. By this means the temperature of combustion is raised from about 1,500°C. (with 10 per cent. excess of air), by 400°-480°C. to 1,900°-1980°C., so that in this way furnace temperatures of 1,400° to 1,500°C. can be attained, as they can when firing with coal. The net efficiency rises from $\dfrac{1{,}500 - 1{,}000}{1{,}500^\circ} = 0{\cdot}33$ to $\dfrac{1{,}980 - 1{,}000}{1{,}500^\circ} = 0{\cdot}66$ that is, it is doubled, so that in ingot-heating furnaces one may obtain efficiencies of 50 to 55 per cent. and heat consumptions of 350,000 to 400,000 Kg. cals. per ton of cold through-put.

This increase of effective heat potential by pre-heating is the more important the higher the working temperature, and renders it possible to apply any fuel to the greatest advantage. By pre-heating to 1,300°C. one could heat an open hearth furnace if the radiation of the flame were sufficient (*i.e.*, with blast furnace gas. *Translator*).

The deficiency of the radiating power can be made good by the addition of coke oven gas, with which any temperature may be attained by adding a sufficient quantity. By adding 20 per cent. of coke oven gas (1,540 Kg. cals.) the same effect may be obtained by pre-heating the air alone to 600° as by pre-heating blast furnace gas in addition. With cold mixed gas in the proportions of 2 cu. metres of blast furnace gas to 1 cu. metre of coke oven gas, the same result is obtained as with cold air in vortex burners.

[4] Hugo Bansen, Rheinhausen-Nrh.: *Errechnung der Arbeitstemperaturen in Metallurgischen Öfen* (Calculations of the working temperatures in metallurgical furnaces); Stahl. u. Eisen, No. 7, Feb. 1922.

By enriching with coke oven gas it is possible to adapt any system of firing in a simple manner for the use of gas only by installation of gas burners, and by increasing the proportion of coke oven gas one can attain any desired temperature and output. The same result can be attained by the addition of tar, tar oil or coal dust, but such methods of working are not so easily adjustable, and in the case of coal dust the arrangements are less simple. On principle, the use of forced draft for gas firing is to be recommended, as it enables the output of the furnaces to be increased by increased firing independently of the cross-section, and is the only satisfactory method of regulating the temperature even though the chambers or burners may be obstructed.

Attempts have been made to simplify the burner by developing it as an injector flame for aspirating the air, but in the case of furnaces it is impossible by this means to achieve complete success, as the burner has to work under excess pressure, the aspirating efficiency is very low and it is impossible to obtain a satisfactory turbulence. If a portion of the air is supplied at higher pressure, the injector burner has no real justification, as an air supply main has in any case to be installed, and the energy required to supply the whole of the air under a pressure of 50 to 100 mm. of water column is less. The plant is particularly simple if a fan or blower is applied directly on the furnace or on the air valve. As a safety device, valves should be built into the gas mains, which cut off the gas supply if the air supply fails.

V. *Pre-heating the Blast.*—When using badly purified gas and a fluctuating gas pressure it was necessary that the blast pre-heating plant should be provided with ample reserves in order to ensure the necessary blast temperature. This was achieved by using four and more separate stoves, long heating periods and wide flues in order to avoid obstruction by dust. When working with highly purified gas well fitting gate-valves can be used, which may be actuated automatically and very rapidly by compressed air. Consequently, it is unnecessary to employ long heating periods, and reversing periods of one hour and less become possible. When using pure gas narrow flues can be used. The gas is first passed through chequer-work of 160 mm., then of 100 and 80 mm. width, and so through chequer-work of smaller and smaller dimensions, with continual increase of the heating surfaces. If the chequer-work is to be fully utilised, the wall thickness should decrease with the width of the passages and with the reversal period. With chequer-work walls of 30 mm. one may increase the heating surface from 10 to 15 sq. metres of heating surface per cu. metre of chequer-work to 30 to 50 sq. metres per cu. metre. Instead of 7,000 sq. metres of heating surface and 750 tons of chequer-work of low efficiency, one can obtain 14,000 sq. metres in the same installation with 400 to 500 tons weight only, which has the same heat storage capacity at full output, and suffices completely for a high rate of production with one stove on gas and one on blast. The effective draught in an air heater of 35 metres height, with a chimney 80 metres high is, however, only 35 mm. water column, with a flue gas temperature of 300°C., and drops with falling flue gas temperature. Even if all unnecessary resistance through sudden decreases in the width of the gas channels are avoided, one can only heat 12,000 to 15,000 cu. metres of gas per hour. If, however, the air and the gas are introduced at a pressure of 100 to 200 mm., the quantity of gas can be doubled and the degree of heating can be increased at will until higher temperatures are

obtained, which can be more uniformly and easily regulated. Disturbances caused by increase of the bonnet temperature to 1,300° to 1,400°C., when heating strongly are avoided by working with 30 to 40 per cent. excess of air, so that not more than 21 per cent. of carbon dioxide is present in the flue gas, and the temperature cannot exceed 1,250°C. By lagging with hard kieselguhr bricks and reducing the number of stoves the wall losses are reduced from 2,000,000 Kg. cals. per hour with four stoves to 500,000 Kg. cals. per hour with 2 units and the efficiency of the heating surface is increased from 90 to 97 per cent. By the use of large heating surfaces and narrow gas channels the flue gas temperature is reduced from 250°-350° to 80°-200°. By this means the efficiency of the firing is increased from 0·8 to 0·88. The total efficiency is thus increased from $0{\cdot}9 \times 0{\cdot}8 = 0{\cdot}72$ to $0{\cdot}97 \times 0{\cdot}88 = 0{\cdot}85$. The gas consumption per 100°C of blast temperature (= 32·4 Kg. cals per cu. of blast) falls, therefore, from $\frac{32{\cdot}4}{0{\cdot}72} = 45$ Kg. cals to $\frac{32{\cdot}4}{0{\cdot}85} = 38$ Kg. cals. per cu. metre of blast. The gas consumption falls from 3·5 to 4 per cent. of the gas production per 100° blast temperature to 2·8 per cent. The hot blast mains should be lined with semi-hard kieselguhr bricks and 200 mm. of fireproof lining. The temperature loss up to the ring main is then 20° only. In order to regulate the temperature in the ring main cold air is often added, the supply valve of which is automatically controlled in such a manner that the temperature is maintained constant.

(*b*) Power Production

I. *The Power House.*—In spite of the fact that its heat consumption is 25 to 50 per cent. higher, the steam turbine competes with the gas engine as a producer of power and blast. It has the advantage over the gas engine with regard to capital cost, working cost, floor space and labour requirements, and enables larger units to be used, as large gas engines of 3,800 to 4,000 kW. represent for the present the maximum development. The steam turbine which requires 4,500 Kg. cals per kWh. is as economical as the gas engine at a price of 0·233 pf. per 1,000 Kg cals. in the gas (1 1d. per therm, *Translator*), and is the only possible choice in works which provide a surplus of blast furnace gas[5]. The conditions are particularly favourable when the steam turbine is used for driving blowing engines. In this case when the load is varied the heat consumption is approximately equal if the rate of revolution is regulated; in a modern turbine and with a vacuum of 96 per cent. attained by cooling the condenser with flowing water, the heat consumption can be maintained at 4,100 to 4,200 Kg. cals. per kWh., inclusive of the requirements of the installation. Under such conditions the steam turbine blower is more economical than a compressor driven by a gas engine, even if the whole of the heat consumption is fully utilised. The gas engine compressor of 3,800 kW. supplying air at 1,650 to 1,300 to 850 cu. metres (at 760 mm. and 0°C.), per minute at a pressure of 1·0 to 1·5 to 2·5 atmos. excess pressure, represents the maximum development so far achieved. During continuous operation its efficiency is not essentially better than that of a turbo-blower in consequence of leaky pistons and valves. By varying th rate of revolution from 2,600 to 3,300 revs. per minute the turbo-blower

[5] Bartscherer· *Gasmaschine oder Dampfturbine* (Gas engine or steam turbine); Archiv. f Eisenhuttenwesen, Vol. 1, 1927/28, D.297.

driven by 4,500 to 8,400 kW. at the blower coupling, can supply the same quantity of air, that is, 2,400 cu. metres (at 760 mm. and 0°C.), per minute at from 1·0 to 2·25 atmos. excess pressure with an efficiency of the blower of from 73·8 to 71·6 per cent. At the maximum rate of revolution and a lower pressure than 2·25 atmos. excess pressure, the amount of air impelled is correspondingly larger. Table II. reproduces data of Wolf and Bartscherer, comparing the results attained with gas and with steam[6].

TABLE II.

COMPARISON OF GAS AND STEAM AS SOURCES OF POWER.

	Electric power production.[1]		Blast.[2]	
	Gas.	Steam.	Gas.	Steam.
Maximum output of power unit kW.	4000	Very large units.	4000	Very large units.
Capital costs[3]:				
Gas engine per 4000 kW. without waste heat boiler ... Mk./kW.	332			
Gas engine per 4000 kW. with waste heat boiler ... Mk./kW.	355		350	
Waste heat turbine .. ,,	130		115	
Steam turbine		224		188
Heat consumption[4] .. k cal/kWh.		4500		4100
Without waste heat boilers ..	4000		4000	
With ,, ,, ,, ..	3000		3000	
Adiabatic efficiency of blowing engine, per cent.			85	81[5]
Operating charges pf/kWh.	0·5	0·35	0·5	0·2
Space requirements ..	2·5 : 1		2·5 : 1	

[1] Bartscherer } Archiv f.d. Eisenhuttenwesen 1927, Part 4, pp. 285 and
[2] Wolf } 297.
[3] The capital costs refer to installed kW.
[4] In the figures for heat consumption, the consumption of the auxiliary engines is included.
[5] The adiabatic efficiency of the turbo-fan appears to be somewhat high.

II. *Steam Boilers*. The older types of fire tube boilers working at 10 to 15 atmos excess pressure can be worked with a production of 25 to 35 Kg of steam per sq metre of heating surface per hour (and 55 Kg. per sq. metre per hour have been attained on occasion)[7] In such boilers, with the help of vortex burners and economisers, an efficiency of 65 to 75 per cent can be attained. The heating surface per unit being comparatively small (about 100 sq. metres), and the output also relatively small, the space requirements are large

As a consequence of the endeavour to obtain a larger output of steam in a

[6] Wolf, Hermann and Bartscherer. *Gasmaschine oder Dampfturbine* (Gas engine or steam turbine): Archiv fur Eisenhüttenwesen, 1927, Part 4, p.285 and 297.

[7] Hugo Bansen, Rheinhausen-Nrh.: *Gluckauf*, 1927.

smaller space together with a higher efficiency, a new type of boiler has been developed, consisting of an upper boiler with five fire tubes and a lower boiler with smoke tubes into which a superheater was built.[8]

The same advantage of compact construction is offered by the marine boiler[9], in which 300 to 350 Kg. of steam can be generated per sq. metre of floor space. By means of narrow smoke tubes, which are in this case placed in the same boiler above two flame tubes, in conjunction with a suction draught, it is possible to accommodate a large heating surface in a limited space. High initial temperatures and a high output from the heating surface of the flame tubes, which is small compared to the total heating surface, are rendered possible by substituting air pre-heaters for an economiser and by the use of vortex burners. In this case also the superheater is situated in the smoke tube.

The practical working of such a boiler of 250 sq. metres heating surface is represented in Fig. 6. At 15 atmos. excess pressure with a steam temperature of 350° to 380°C., and a steam generation of 35 to 50 Kg. per sq. metre of heating surface, a boiler efficiency of 80 to 83 per cent. is attained. The cost of such a boiler is 240 marks (£12) per sq. metre of boiler heating surface, and 500 marks (£25) per sq. metre for the total installation, corresponding to 10,000 marks (£500) per ton, per hour, for the maximum obtainable steam output.

For larger units, finally, with pre-heating of the gas and the air, the water-tube boiler with inclined tubes is used working at 35 atmos. excess pressure and 400°C. steam temperature and generating about 80 Kg. of steam per sq. metre of heating surface with an efficiency of 80 to 86 per cent. In order to achieve such high outputs of steam an exhaust draught is also necessary in this case.

Fig. 7 shows the heat flow and the heat contents and temperature of such a boiler in which the gas and air are pre-heated to 400°C. In order to show clearly the advantages of pre-heating the gas and air, the theoretical flame temperatures for various degrees of pre-heating are shown in the figure. At a net calorific value of the blast furnace gas of 1,038 Kg. cals. per cu. metre, these are as follows:—

(*a*)	Gas and air pre-heated to 400°C.	= 1,765°C.
(*b*)	,, ,, ,, ,, 300°	= 1,680°
(*c*)	,, ,, ,, ,, 250°	= 1,640°
(*d*)	Air alone pre-heated to 400°	= 1,608°
(*e*)	,, ,, ,, ,, 300°	= 1,570°
(*f*)	,, ,, ,, ,, 250°	= 1,545°
(*g*)	Neither gas nor air preheated	= 1,450°

(*d*) and (*e*) are of theoretical interest only, as pre-heating the air to 300° to 400° would cause a higher temperature in the flue gases, and consequently a lower efficiency. In the case of (*g*), an efficiency of 86 per cent. is only possible if an economiser is added. By adding oil or coal dust to the gas the radiation of the combustion gases, and consequently the steam generation from the heating surface can be increased still further.

The capital costs for an installation working at 35 atmos. amount to about

[8] *Stahl. und Eisen*, 1925, p. 1,225, and 1926, p. 1,383.

[9] See Archiv für Eisenhüttenwesen, Part 4, Vol. 1, *Gasmaschine oder Dampfturbine* (Gas engine or steam turbine).

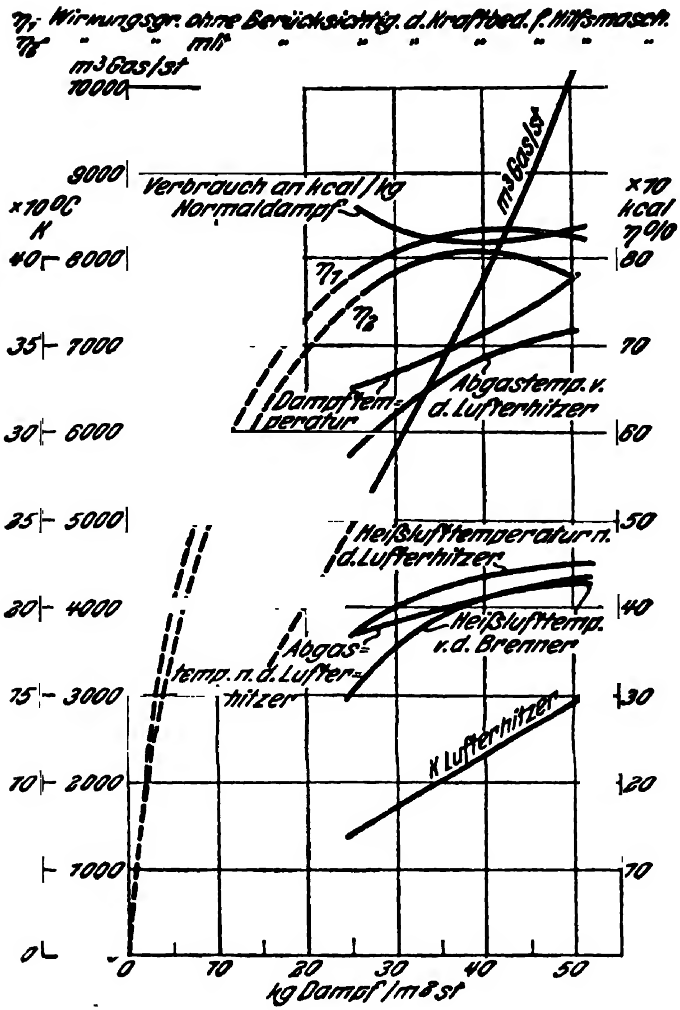


Fig. 6.

WORKING RESULTS OF A MARINE BOILER FIRED WITH BLAST FURNACE GAS

N_1 = Efficiency ignoring the power requirements for auxiliary machinery.
N_2 = Efficiency deducting power requirements for auxiliary machinery.
m^3 Gas/St = Cu. metres of gas per hour.
Verbrauch an k.cal/kg Normaldampf = Consumption of Kg. cals. per Kg. of normal steam.
Dampftemperatur = Temperature of steam.
Abgastemp. v. d. Lufterhitzer = Temperature of flue gas in front of air pre-heater.
Heisslufttemperatur n. d. Lufterhitzer = Temperature of hot air behind air pre-heater.
Heisslufttemp. v. d. Brenner = Temperature of hot air in front of burners.
Abgastemp. n. d. Lufterhitzer = Flue gas temperature behind the air pre-heater.
Lufterhitzer = Air pre-heater.
Dampf = Steam.

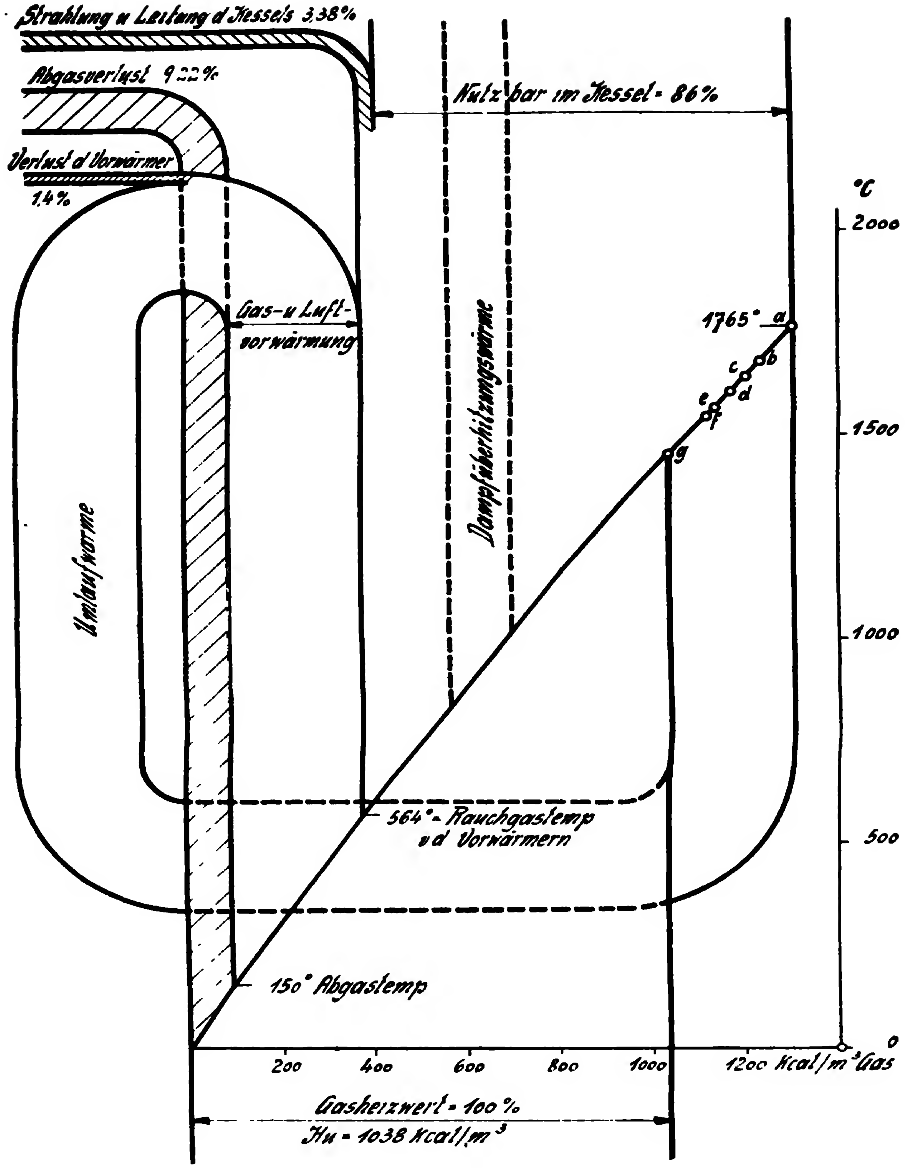


Fig. 7

DIAGRAM OF HEAT FLOW, HEAT CONTENTS AND TEMPERATURE IN A BOILER FIRED BY BLAST FURNACE GAS IN WHICH THE GAS AND AIR ARE PRE-HEATED TO 400°C., AND WITH 23·8 PER CENT. EXCESS OF AIR

Strahlung u. Leitung d. Kessels	=	Radiation and conduction losses from boiler.
Abgasverlust	=	Flue gas losses.
Verlust d. Vorwarmer	=	Loss in pre-heaters.
Nutzbar im Kessel	=	Useful heat in boiler.
Gas- u Luft-Vorwarmung	=	Pre-heating gas and air.
Umlaufwärme	=	Circulating heat.
Dampfuberhitzungswärme	=	Superheat of steam.
Rauchgastemp v.d. Vorwarmern	=	Smoke gas temperature in front of pre-heaters.
Abgastemp.	=	Flue gas temperature.
Gasheizwert	=	Calorific value of gas.
Hu	=	Lower calorific value.

800 marks (£40) per sq. metre of heating surface, corresponding to 10,000 (£500) per ton of steam per hour at maximum output.

An evaporating plant, the condensed vapours from which can be used for the feed water, combined with a further pre-heating of the feed water by bleeding low pressure steam to 135°C., increases the total efficiency of the plant by 5·2 per cent.

With complete condensation turbines, and fuel at 0·25 pf. per 1,000 Kg. cals. (11·8d. per therm, *Translator*), a 35 atmos. installation works as cheaply as an 18 atmos. installation, the saving of fuel being balanced by higher capital charges. If, however the feed water is pre-heated by low pressure steam, the advantage lies with the 35 atmos. installation.

A greater economic advantage with higher pressure is attained when considerable quantities of low pressure steam are withdrawn, or by the use of back pressure turbines. As, however, the condensed water cannot usually be recovered in such plants, the preparation of the feed water entails certain difficulties.

III. *Waste Heat Boilers.*—In gas engines a heat efficiency of 3,000 Kg. cals. per kWh. is only obtainable by crediting waste heat steam (1·2 to 1·5 Kg. per kWh.). Waste heat boilers with pre-heating of the feed water, and superheaters generate on the average 15 to 20 Kg. of steam per sq. metre of heating surface. When working at 15 atmos. excess pressure and steam superheating to 400°C., the capital costs are 475 marks (£23 15s.) per sq. metre of heating surface for the total installation, corresponding to 23,800 marks (£1,190) per ton of steam per hour at maximum output, that is, more than double the cost of gas-fired boilers. The operating costs are also two to three times as high.

The production of waste heat steam is irregular owing to engines being out of action or to repairs of the waste heat boilers, so that a turbo-generator installation driven entirely by waste heat steam would have a restricted value only for dealing with peak loads. It would be insufficient in those cases in particular when increased output was necessary owing to machines being at standstill, and additional gas fired boilers would, therefore, be necessary.

IV. *Production of Blast.*—The steam turbo-blower which can be used at high speed for supplying air at a high pressure at relatively low cost, renders it possible to supply a steady quantity of air to furnaces working at high output.

As the output of blowers seldom corresponds to the requirements of a single furnace, and that of a gas-driven compressor never, blowing engines are now frequently connected with a collective main. The air pressure is maintained at such a level that it corresponds to the requirements of the most heavily driven furnace. In consequence, the average power requirements are higher, but this fact is more than compensated by the higher load factor. The furnaces are supplied with air by adjustable throttle valves, and are completely independent of the air compression plant. As the air main is constantly under pressure, any danger of explosion on stopping a furnace is impossible.

The position already explained regarding the relative advantages of the use of gas or of steam also applies to blowers for steel works working at 2·5 to 3·0 atmos. excess pressure. Steam turbine blowers entail less expense in spite of larger heat requirements. In steel works, compressors supplying

compressed air are usually only present as small units. As the individual demands only developed gradually, small piston compressors with electric drive were installed from case to case. In a new works it would be advisable to centralise the compressed air production in order to economise current and supervision.

(c) FURNACES AND HEAT PRODUCTION

I. *Coke Ovens and Coke Oven Gas.*—The development of the regenerative oven made it possible to heat it with blast furnace gas by providing a further pair of chambers for the gas and by enlarging the gas flues. By retaining the coke oven gas mains and burners the combined oven was evolved which could be used at will with lean or rich gas. The lean gas oven was developed along the same lines as the rich gas oven, with chambers up to 4 metres in height and up to 13 metres long. In order to retain the size of the coke and in order to render repairs possible, the width of the coking chamber is never less than 400 to 430 mm. The chambers are lined with silica bricks. The coking periods are from 17 to 24 hours according to the character of the coal. More especially in the case of coke ovens attached to steel works which are supplied with coal from various pits, an ample storage capacity and mixing plant is necessary in order to ensure the production of a uniform mixture of coal. Both the coking period and the heat consumption vary greatly with the character of the coal. A universal guarantee of the heat consumption is, therefore, impossible[10]. The experiments of Terres and his co-workers show that the heat consumption per Kg. of coal up to 1,000°C. varies from 200 to 400 Kg. cals. per Kg., the average being 300 Kg. cals. per Kg. The course of the process is partly endothermic and partly exothermic, and together with the heat supplied by the fuel gas has naturally a very great influence on the coke production and the formation of the by-products.

Heating must be carried out with a carefully purified blast furnace gas at constant pressure. The quantity of gas must be regulated in accordance with the variations in its calorific value, or coke oven gas must be added in order to equalise these. By regulating the draught, the calorific value should be kept as constant as possible, and not below 3,800 Kg. cals. The whole of the evolved gas is utilised in the steel works and rolling mills. If no gas holder is available, any excess is passed through an excess pressure regulator into the boiler heating gas main. The coke oven battery of a steel works should be of such a size that it can supply the necessary gas for heating the steel and the rolling mill furnace with the addition of blast furnace gas. As will be explained later, it is profitable to supply any excess of gas to long distance mains. It is unnecessary to desulphurise the gas, but if it is to be transmitted over long distances it is desirable to remove the naphthalene in order to avoid difficulties in the mains.

II. *Open Hearth Furnaces.*—According to Bansen[11], the heating of open

[10] Rummel, K. and Oestrich, H.: *Wärmetechnische Bewertung und Überwachung von Kokereien* (The thermal testing and control of coke ovens); Archiv für Eisenhüttenwesen, Vol. 1, 1927/28, A and D 403.

[11] Hugo Bansen, Rheinhausen-Nrh.: *Leistung und Wirkungsgrad als Unterlagen für Bau und Berechnung der Siemens-Martinofen* (Output and efficiency as bases for the construction and design of open hearth furnaces); Stahl. u. Eisen, Vol. 45, 1925, p. 702

hearth furnaces is characterised by the fact that the exit temperatures of the flue gases from the furnace are higher than the theoretical temperature of combustion of most of the gases used as fuel if burned with cold air. An effective heat gradient is therefore only obtained by utilising the heat of the flue gases; therefore, if the regenerating chambers have a temperature of 1,000° to 1,200° C., the output of the furnace is increased by 20 per cent. without any addition to the gas supply, with a corresponding decrease of the heat consumption per ton of steel.[12]

In the furnace chamber the heat is mainly transmitted by radiation, and the radiation from carbon dioxide and steam is insufficient for the purpose.

It is necessary that the mixture of coke oven gas and blast furnace gas should be pre-heated to an exceptional extent so that finely divided carbon may be formed by the interaction of methane, carbon dioxide and steam, a reaction which becomes marked at temperatures of more than 1,100°C.[13]

The radiation of the flue gases alone of the mixed gas, namely, carbon dioxide and steam, does not suffice for the necessary heat transference, but according to Schack, the finely divided carbon absorbs heat at a very low temperature difference by contact with the flue gases, and radiates this heat to the bath and the furnace walls.

The conversion of furnaces heated with producer gas to heating with mixed gas therefore entails an increase of the heating surface of the gas chambers, and stronger heating by utilisation of about 40 per cent. of the flue gas. A mixed gas is used containing about 1 cu. metre of coke oven gas and 2 cu. metres of blast furnace gas of approximate net calorific value 2,000 Kg. cals. Mixing is either carried out for all the furnaces jointly by leading the gases into a main, or preferably, at the furnace itself, so that a stronger mixture can be prepared if necessary. The furnaces may be heated up and kept hot by blast furnace gas only. The supply pressure of the gas must be regulated so that a uniform supply is ensured. Occasionally, 10 to 20 per cent. of producer gas is added in order to increase the radiation of heat, or 5 to 10 gm. of tar per 1,000 Kg. cals. in the gas are sprayed into the gas supply[14]. It is preferable to work with mixed gas rather than with pure coke oven gas although the construction of the furnace is simple in the latter case. When pre-heating the gas and air in the case of mixed gas, one can work with flue gas temperatures of 400°C., and thus avoid the use of waste heat boilers. When working with mixed gas the variations of the calorific value of the coke oven gas do not cause as much difficulty even if it falls below 4,000 Kg. cals. An ample supply of blast furnace gas to the steel works must be ensured, and, if necessary, the steam boilers must be fired with coal. For stationary furnaces the usual charge is 60 to 80 tons, and for tilting furnaces 100 to 200 tons. Recognition of the fact that large depths of the bath exercise no

[12] Hugo Bansen, Rheinhausen-Nrh.: *Einfluss der Vorwärmung von Gas und Luft auf den Gang des Siemens-Martinofens* (Influence of the pre-heating of the gas and air on the operation of open hearth furnaces); Bericht des Stahlwerksausschusses (Report of the Steel-work Committee), V.d.E., No. 92.

[13] Report No. 117 of the Steel Works Committee, V.d.e. of 13.7.26, p. 8.

[14] Friedrich Stein, *Zusatz von Karburierungsmitteln bei mit Mischgas beheizten S.M. Öfen* (The addition of carburetting agents when heating open hearth furnaces with mixed gas); Archiv f. Eisenhüttenwesen, Vol. 1, 1927/28, B. 629

unfavourable influence has led to an increase of the weight of charge to 2 tons per sq. metre of hearth area for ovens of average size, and of 3 tons and more for tilting surfaces. The normal output is 250 Kg. per sq. metre per hour, and often exceeds 300 Kg. per sq. metre per hour.

The heat consumption when working with mixed gas is 1·25 to 1·4 million Kg. cals. per ton.

An increase of the hourly output has been attained by increasing the weight of charge, as a 10 per cent. greater charge is equivalent to a 5 to 7 per cent. greater output per hour and increased gas supply per hour. The use of forced draught and suction of the exit gases assist in this sense that they enable the output of the furnace to be maintained, even with old furnaces.

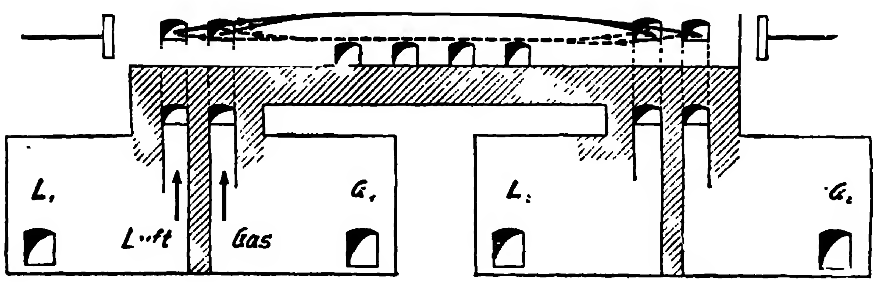


Fig. 8.

REGENERATIVE REVERBERATORY FURNACE

Luft = air.

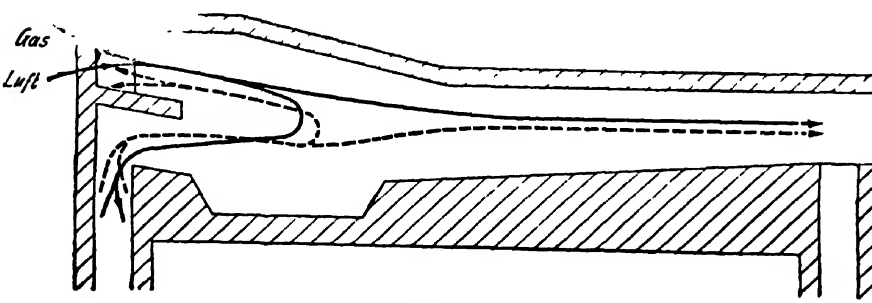


Fig. 9.

FURNACE WITH HORSE-SHOE FLAME

Luft = air.

The remelting of ferro-manganese as an addition in the ladle is carried out in reverberatory furnaces with coke oven gas and air pre-heated to 200°C., with an output of 150 to 200 Kg. per sq. metre of hearth area per hour. Working with a regulated gas and air supply, adjustment with the help of measuring instruments and temperature control of the chambers has done more to increase the output than special construction of the furnace ports and chambers.

III. *Rolling Mill Furnaces.*— We have already shown by what means blast furnace gas can be adapted technically and economically for all heating operations by pre-heating the gas and air or by admixture with coke oven gas. Its application about twenty years ago first led to the development of the

regenerative furnace. Reversible firing in the manner used in the open hearth furnace from port to port is certainly suitable for open hearth furnaces which are charged discontinuously. Its adaptation to counter-current conditions in the reheating furnace was attended with difficulties. Attempts were made to solve the problem by many methods; for example, by the development of a twin hearth (Fig. 8), with delayed combustion, so that the heat was mainly developed at the central discharge doors. Siemens used the divided horseshoe flame (Fig. 9), with which one portion of the exit gases from the soaking hearth was re-aspirated into the chambers at the head of the furnace whilst the pre-heating portion was heated in counter-current to the charge. Latterly, directly heated reverberatory furnaces are once more being

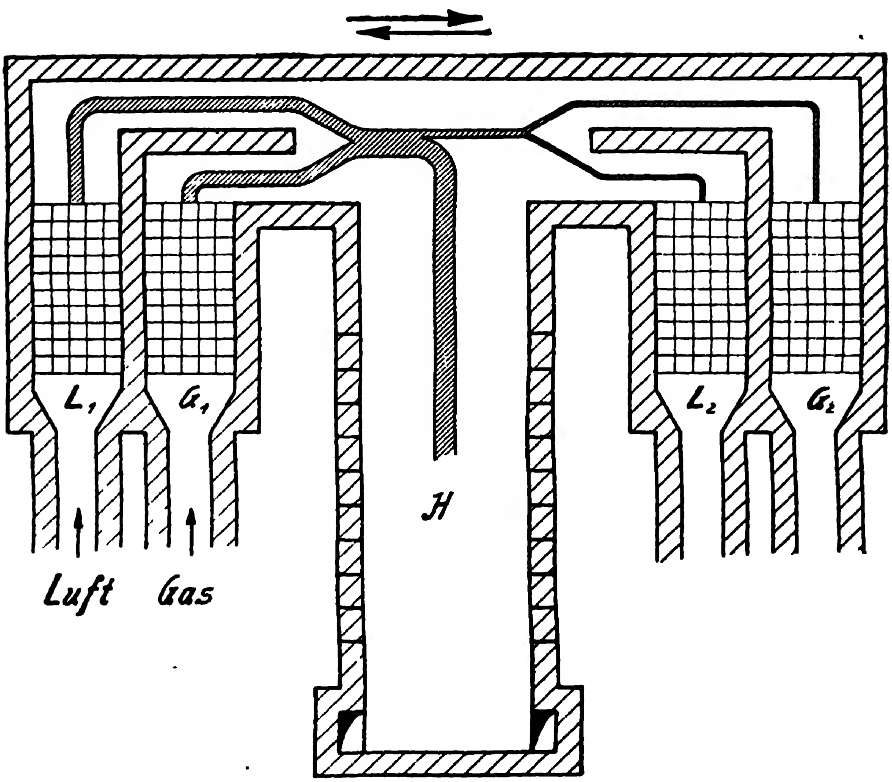


Fig. 10.

REVERBERATORY FURNACE WITH REGENERATIVE HEATING OF CHAMBERS

Luft = air.

constructed in various forms[15], in which a flame is produced in a combustion chamber in front of the hearth from pre-heated gas and air, and is mainly carried over the hearth *H* in counter-current; a portion of this flame is, however, aspirated into the other pair of chambers in order to supply the heat necessary for pre-heating the gas or air to such a degree that the temperature of the exit gases is 300°C. (Fig. 10).

[15] U.S. Patent No. 483,752 of 4.10.1892, Jacob T. Wainright; Method of working heat regeneration, Fig. 3.

In these cases the air alone is sometimes heated to an exceptionally high temperature, and the gas is used cold or is merely pre-heated in the regenerator by direct flame and the waste heat from the hearth is used for pre-heating the air by means of a recuperator. As the temperature of the gas discharged from the in and out furnaces must be maintained at more than 600°C. in order to attain a high output from the furnace and uniform heating, this arrangement is particularly advantageous from the standpoint of thermal economy. The addition of coke oven gas enables the construction of the furnace to be simplified considerably. If it is possible to work with very rich mixtures, the use of gas burners and cold air is sufficient. In order to avoid heat concentration at the soaking hearth, and in order to be able to thoroughly warm the ingots from the commencement, the burners are distributed along the furnace (Fig. 11). The furnace is then developed as a simple heating flue

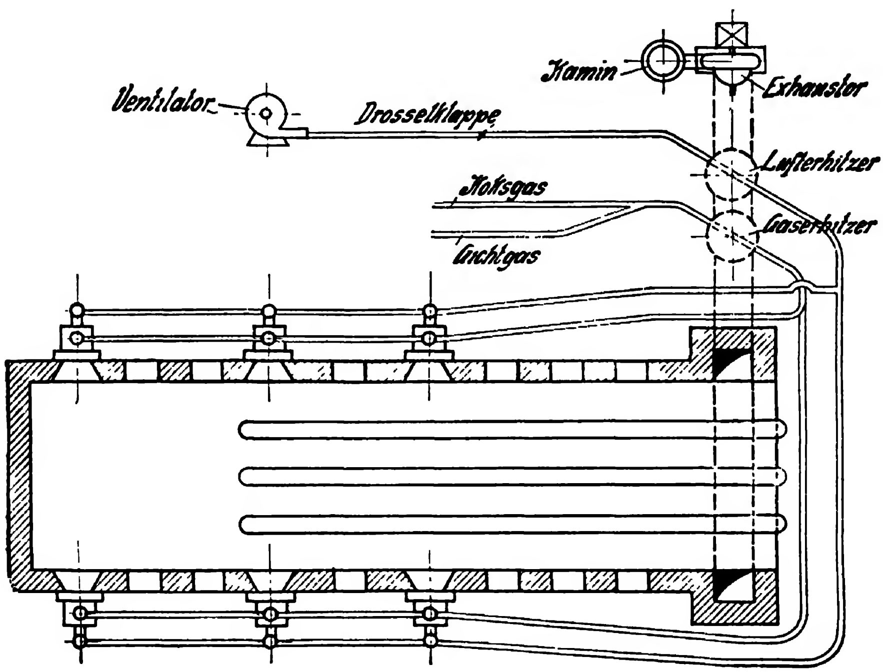


Fig. 11.

REVERBERATORY FURNACE WITH GAS BURNERS

Ventilator	=	Blower.
Kamin	=	Chimney.
Exhaustor	=	Fan
Drosselklappe	=	Throttle valve.
Lufterhitzer	=	Pre-heater for air.
Gaserhitzer	=	Pre-heater for gas.
Koksgas	=	Coke oven gas.
Gichtgas	=	Blast furnace gas.

without any refractory filled lower chambers. Various forms of heater have received attention in Europe, although they have hardly yet been introduced, such as adjustable plate heaters[16], or recuperative tubular heaters of heat

[16] Waldemar Dyrssen, *Mining and Metallurgy*, January, 1928, pp. 12 to 17.

resistant steel, which may be erected near the furnace similarly to a waste heat boiler, and from which gas and air are carried to the burners through mains lined with heat-insulating brickwork, as indicated in Fig. 11. By such means it will be possible to develop the heating furnace as a never-failing heat engine adaptable to the highest peak outputs, particularly if the removal of the flue gases is carried out by exhaust fans instead of by a chimney, and is thus rendered more controllable.

The soaking pit, one of the most essential contrivances between the steel works and the rolling mill, is, when fired by coal, difficult to operate, variable with regard to the temperature of the successive chambers and expensive in upkeep[17].

With the regenerative gas furnace it is difficult to supply the fluctuating demands for heat supply and temperature caused by irregular charging with cold and warm ingots, and such a furnace takes up much space. The unheated soaking pits cool when uncharged and on Sunday, and reduce the average temperature of the ingots by 50°C., through heat losses from the walls. Therefore, the application of group heating by means of gas burners supplied with mixed gas represents an advance. When out of use, and when hot ingots are introduced, the chambers can be maintained warm by blast furnace gas only, and after the introduction of cold ingots, can rapidly be heated up by the addition of coke oven gas to the blast furnace gas. In the case of individual chambers, at any rate, pure coke oven gas gives rise to excessive local heating and uneven heating in general.

The operation of heating furnaces in rolling mills is rarely a continuous process. The charges are introduced irregularly, sometimes hot and sometimes cold; the rolling mill requires ingots of various sizes and in varying quantities when the section of the output is changed.[18] These conditions deserve most careful attention. They lead to the recognition of the fact that the necessary adjustability and ample heat supply for maximum outputs and cold charges are lacking. The furnace is run until the rolling mill engine, irregularities in dimensions and quality, or a breakage, compel it to stop. All these difficulties can be overcome by heating by mixed gas under pressure, by increasing the cross-section of the flues, by flue aspirators, and so forth. In regenerative furnaces fired by blast furnace gas and by mixed gas, and with cold charges, the gas consumption amounts to 350,000 to 450,000 Kg. cals. per ton according to the output and construction of the furnace, and with hot charges to 200,000 to 300,000 Kg. cals. per ton. By merely increasing the supply and withdrawal of gas, normal outputs of 250 to 350 Kg. per sq. metre of hearth area per hour can be attained with any charge, and exceptional outputs up to 500 Kg. per sq. metre.

IV. *Heating Furnaces.*—The requirements and outputs of these are too

[17] Hugo Bansen, *Die Zusammenhänge des Tiefofens mit der Betriebs- und Wärmewirtschaft* (The effect of the re-heating furnace on manufacturing and thermal considerations); Mitteilung der Wärmestelle (Communication from the Heat Laboratory), No. 59, of 22.4.1924.

[18] A. Koegel, *Einfluss von Angebot und Nachfrage auf Leistung, Grösse und Wärmeverbrauch von Stossöfen* (Influence of supply and demand on the output, size and heat consumption of reverberatory furnaces); Ausschuss für Betriebswirtschaft (Committee for Works Management), V.d.E., No. 13, of Nov. 1926.

various for the description of particular cases. Every requirement of heat supply and output can be met by means of blast furnace gas, with or without pre heating, and with or without the addition of coke oven gas. The supposedly necessary reducing flame in furnaces for heating sheet iron to redness can be rendered unnecessary by avoiding an uneven temperature or too high a temperature by ensuring sufficient radiation. For low working temperatures it is frequently advantageous to pass both the flame and the materials in the same direction. Coke oven gas is the most suitable fuel for small furnaces and heat engines. For pre-heating the air, an air jacket around the chimney is frequently sufficient. In such cases the chimney must be thin-walled, or may be constructed of fire-proof sheet steel where required.

V. *Various Heating Contrivances.*—Pig iron and steel ladles are best dried in position with a pressure gas burner in a cover which can be lowered and which is lined with brickwork so that an inverted multiple flame pre-heats the ladle to 600° to 800°C. Converters are warmed whilst upright, in three

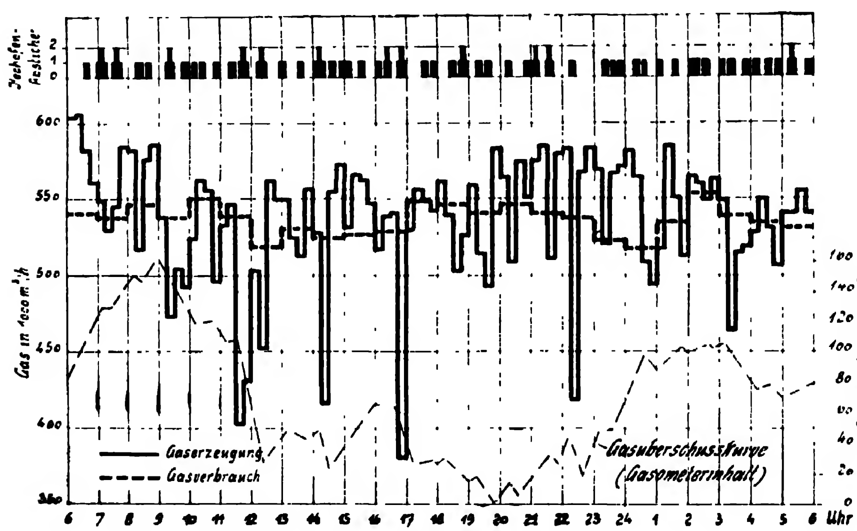


Fig. 12.

PRODUCTION AND CONSUMPTION OF BLAST FURNACE GAS

Höchofen-Abstiche = Tapping periods of furnaces.
Gaserzeugung = Gas production.
Gasverbrauch = Gas consumption.
Gasüberschusskurve = Gas excess curve.
Gasometerinhalt = Contents of gas holder.
Uhr = O'clock.
Gasinhalt = Gas contents.

hours, by a pressure gas burner which is introduced in place of the bottom plate. The tar is burned away by excess of air. Between batches they are kept warm whilst in an inverted position by the ascending flame of a movable burner inserted in the throat. Drums for drying sand are heated by a flame passing in the same direction as the evaporated water vapour with an evaporation efficiency of 50 per cent. if complete dryness is not required. The size of the flame must be adjusted according to the varying moisture contents.

Blast furnace gas is largely used for drying the moulds in foundries. It is only economical to heat roasting furnaces for spathic iron ore or lime kilns with blast furnace gas if surplus gas is available. These operations require the addition of coke oven gas, and if high outputs are required must be carried out with control of flue gases, mechanical conveyors and forced draught

(*d*) GAS SUPPLY AND REQUIREMENTS

In considering the blast furnace as a gas producer, we noted the possible aperiodic variations of the gas output with time. Fig. 12 is a diagram representing the total gas production of seven blast furnaces during one day with scaffolding troubles, and the effect on the gas production of the stoppage of the blast during the indicated periods of tapping the charge. Over a long period production varies within limits of $\pm$ 10 per cent., whilst over shorter periods variations amount to 15 per cent. and more. On the other hand, the gas is needed to supply heat for the most various metallurgical processes not immediately connected with the blast furnaces, but all of which may be operated by blast furnace gas, as already described. In the case in question, these heat requirements are indicated by the dotted line. The possibilities of using blast furnace gas for these various operations in an iron and steel

TABLE III.

PRODUCTION OF BLAST FURNACE GAS

1 tonne Basic Pig Iron. 3750

CONSUMPTION OF BLAST FURNACE GAS

Production per tonne of Basic Pig Iron		Gas consumption	Gas consumption of products in cu. metres per tonne of Basic Pig Iron			
Product	Tonne	Cu. metres per tonne of product	Per individual stage of operations	Total production		
Basic Pig Iron, including treatment of ore, blast furnace dust and slag	1	1448 (1320 + 128)	1448 (1320 + 128)			
Bessemer steel, including ground phosphate .	0·88	279 (235 + 44)	260 (210 + 50)			
Rolled steel from Bessemer steel	0 72	1250	900	2608		
Open hearth steel from scrap iron .. .	0·44*	400	175			
Rolled steel from open hearth steel . ..	0 36	1250	455	630		
Coke, including by-products . .	0·31	1160 1000 + 160)	362 (310 + 52)	362	3600	
Surplus (Loss)		•			150	3750
Column ..	1	2	3	4	5	6

* 0·5 tonnes Open Hearth steel per tonne of Bessemer steel

works producing basic pig iron allow of an equilibrium between gas supply and gas consumption, as shown in Table III., Column I. Per ton of basic pig iron, one can produce 880 Kg. of Bessemer steel and 440 Kg. of open hearth steel, so that the supply of crude steel is provided as to 67 per cent. by Bessemer steel and as to 33 per cent. by open hearth steel, and the necessary coke oven gas for heating the open hearth furnaces can be produced on the works, and

thus one obtains 1 ton of rolled iron from 1 ton of basic pig iron and the gas from about 1 ton of coke. In the best conducted operation of producing gas, a gas loss of 3 to 7 per cent. occurs, due to the inevitable losses through leakages, through stoppages, and when gas is blowing off. For this reason, and through the use by the blast furnace for heating the blast (20 to 25 per cent.), and for the blowing engines (9 to 14 per cent.), there remain 50 to 55 per cent. of the gas production, that is, about 1,800 to 2,000 cu. metres of gas per ton of pig iron, which are available for other purposes. Each ton of open hearth rolled steel from scrap requires 1,750 cu. metres of blast furnace from the excess of the gas from the production of the basic pig iron, whilst when producing rolled iron by the pig iron ore process the gas requirements are supplied in the production of the necessary pig iron. If, therefore, an iron and steel works operates basic iron blast furnaces and also furnaces producing commercial, pig iron, the management will desire to find an outlet for the excess of gas by means of further refining processes, by auxiliary processes such as lime kilns, cement works or by power supply in the form of current or coke oven gas. It may also attempt to equalise output and demand by an increased production of open hearth steel from scrap from other works, or if the prices for scrap are low it will endeavour to reduce the coke consumption of the blast furnace by the considerable use of scrap. The less gas is available the greater will be the tendency to electrify, but if the gas supply is abundant the rolling mills will continue to be driven by steam power. Fig. 13 shows a flow sheet of the gas distribution to the various departments of a works. There are as many different possibilities of organising the works as there are methods of equalising the heat requirements and demands. The main principles of a rational policy with regard to gas production and utilisation are as follows:—

> A supply of gas should above all be secured for the works departments, and should be methodically supplied to those which (1) are dependent on gas alone for the heat supply necessary for their operation apart from specially purchased fuel, and (2) are dependent on gas for their most intensive supply of energy and highest heat potential.

The departments coming under heading (1) are the gas engines and under heading (2) are (*a*) the Cowper stoves; the hot blast supplies the highest working temperature in the blast furnace and effects economy of coke; (*b*) the coke ovens. If 1,000 Kg. cals. in the form of blast furnace gas of lower calorific value are used per ton of coke, about 1,400 Kg. cals. of coke oven gas of higher specific calorific value are saved, together with which a further quantity of blast furnace gas can be utilised for the following purposes:—(*c*) to heat the open hearth furnaces, and thus to avoid the use of coal and high gasification costs, and to simplify the operation of the furnaces, and in the same way (*d*) to supply heating furnaces. Furthermore, the blast furnace gas may be used for (*e*) production of coke oven gas for long distance gas supply, which is the most profitable enterprise. The rest of the blast furnace gas is sent to the boilers. Coal should always be used for the production of electric current and for driving the rolling mills, as it is certainly the simplest and cheapest fuel for this purpose, and does not disturb the continuity of operations.

The furnace worker should above all things be a metallurgical assistant, that is, a smelter or heater, but not a stoker. This principle is emphasised in

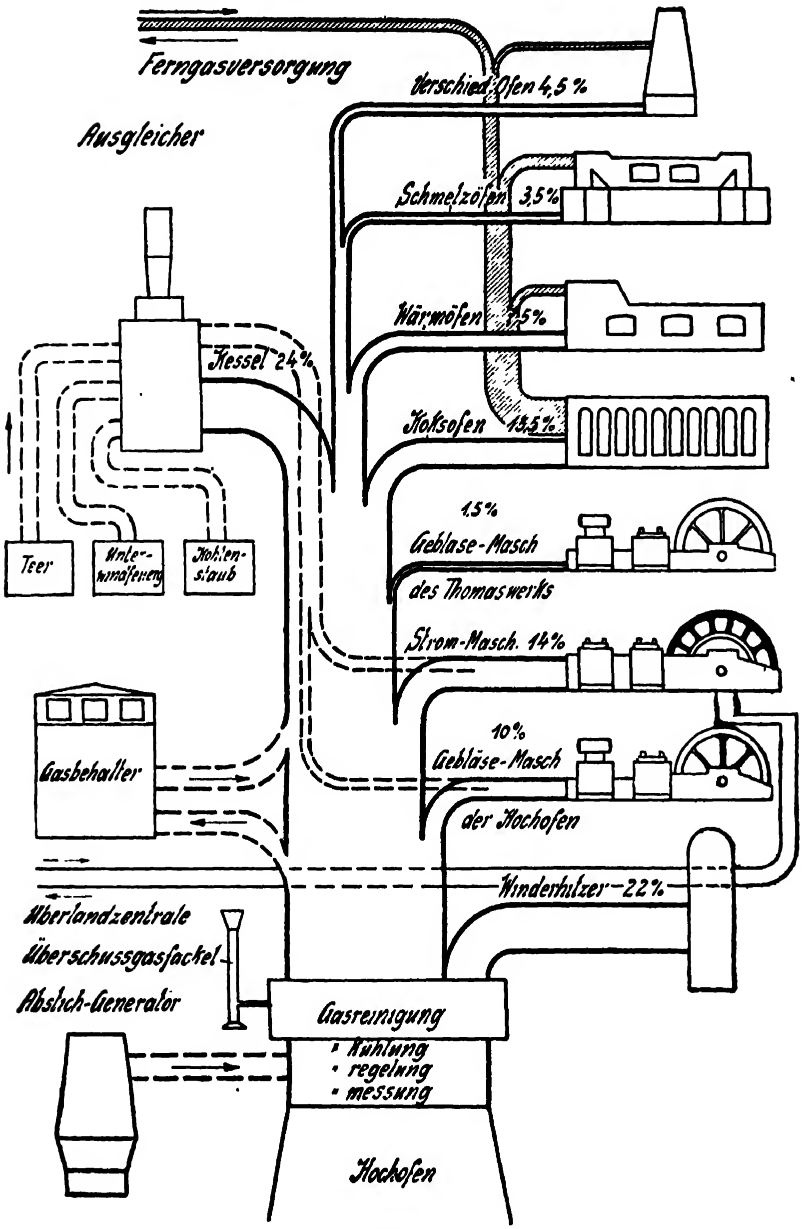


Fig. 13.

DISTRIBUTION OF BLAST FURNACE GAS

Ferngasversorgung	=	Long distance gas supply.
Verschied. Öfen	=	Various furnaces.
Ausgleicher	=	Equalisers.
Schmelzöfen	=	Melting furnaces.
Wärmöfen	=	Heating ovens.
Kessel	=	Boilers.
Koksöfen	=	Coke ovens.

Teer	=	Tar.
Unterwindfeuerg	=	Forced draught furnace.
Kohlenstaub	=	Pulverised coal.
Gebläse-Masch. des Thomaswerkes	=	Blowing engines for converters.
Strom-Masch	=	Dynamos.
Gebläse-Masch der Hochöfen	=	Blowing engines for blast furnaces.
Gasbehälter	=	Gas holders.
Winderhitzer	=	Cowper stoves.
Überlandzentrale	=	To public power station.
Überschussgasfackel	=	Surplus gas burner.
Abstich-generator	=	Slagging gas producer
Gasreinigung	=	Gas purifiers.
,, Kuhlüng	=	Gas coolers.
,, Regelung	=	Gas regulators.
,, Messung	=	Gas meters.
Hochöfen	=	Blast furnaces.

Fig. 13. The gas passes from the blast furnace to the cleaning plant. A uniform pressure should be maintained in the crude gas main by throttling. In case of excessive production, uniform pressure is maintained by rejection through a waste pipe with pressure gas burners. The washing plant is the distributing centre for gas supply, and in this department the whole of the gas which is produced is collected and measured. Supervision is improved by indicators showing the air supply to the blast furnaces, the stopping and starting of the same and the load on the various works departments. The gas production of the blast furnace is 1·35 times the air supply The installation is completed by direct telephonic communication with the blast furnace and with the gas consuming departments. The Cowper stoves tend to lose their function of heat equalisers for gas when the blast furnaces are working at high production, this tendency is increased by large heating surfaces and small weight of chequer-work, features which enable the blast rapidly to be reversed. The further main load consists of the blowing engines and the dynamos, at least in so far as they are driven by gas. When they are driven by steam they are best considered, together with the boilers, as belonging to the regulating system. Open hearth furnaces and heating furnaces utilise blast furnace gas according to requirements, and the maintenance of a sufficient supply pressure is, of course, necessary in order to cover exceptional production.

The boilers may conveniently be used as the only method of adjustment, and therefore, if the rolling mills are driven entirely by electricity, a portion, at least, of the electric power station is driven partially by gas engines and partially by steam turbines. A deficient supply of gas, which occurs fairly frequently, is most simply supplemented by firing with tar or with tar oil, in the case of which the higher costs of fuel are relatively unimportant compared with the small capital costs and the fact that they can always be applied instantaneously. A deficient gas supply over a long period is supplemented by supplementary firing with coal on forced draught grates, or with coal dust. Steam storage is not much used in iron and steel works, as there is no demand for steam at moderate pressure; nor is feed water heat storage much used because it only enables heat to be stored to a moderate extent, over a long period, and does not constitute heat storage for large peak loads.

If one of the blast furnaces is idle for a considerable period, the operation of the rest of the furnaces can to a certain extent be made to compensate

for that of the one standing idle by increased blast, if the arrangement of the furnace layout renders this possible and if a higher blast pressure is available. Nothing should, however, be permitted which destroys the balance of the furnaces. The working of the furnaces can also be adjusted to the requirements of blast furnace gas by employing a higher proportion of coke and a lower blast temperature, in so far as it is possible to accommodate the larger quantity of blast. In spite of the higher fuel costs, economic working is maintained by the higher efficiency of the gasification to carbon monoxide at a lower flue temperature, and avoidance of expensive regulating methods. The Halberg experiments,[19] show that it is possible to effect this additional gasification by blowing coal dust without metallurgical effect into a satisfactorily operating furnace through or above the tuyères. A further method of equalising the gas main system in order to equalise the gas supply is the slagging gas producer. This can be suddenly heavily overloaded by automatic regulation of the air supply, and can be left idle for considerable periods. In order to improve the efficiency of the producer and to reduce the flue temperature, it is desirable to add a small proportion of ore and blow with hot air in order to facilitate formation of slag, more particularly if the furnace is working at a low through-put. There is no objection to using non-coking coals, or cinders containing fuel, in the producer, if only one avoids abrasion, even in the case of coke The producer is best connected to the crude gas main. The charging of the producer must be so arranged as to economise labour as far as possible, so that the operating costs remain low, even when the through-put is small.

The high installation costs of a gas holder, which amount to 6,000 to 12,000 marks per 1,000 cu. metres capacity, in sizes of 20,000 to 200,000 cu. metres, necessitate that these should be traversed by 400 to 850 times their capacity in gas annually in order to meet the capital charges. It will therefore only be possible to employ a gas holder profitably in those rare cases in which, as in Fig. 11, the gas requirement and gas consumption curves continually intersect to such an extent that the peak production of gas can continuously be utilised for off-peak loads. The erection of a waterless gas holder of 1,000 cu. metres capacity can only be justified if by its means 110,000 marks can be saved at the boilers = 5,000 to 7,000 tons of supplementary fuel. The case is otherwise for coke oven gas, which represents a price four times greater than the equivalent of coal, and an economic value for steel works which is seven to ten times as high.

Although it is usual, for the sake of simplicity of calculation, to consider an average price for gas on the basis of its calorific value in terms of coal, special valuations must always be used for exact calculations of production cost. Both blast furnace gas and coke oven gas have no definite price, as they are not produced for their own sake, but have only a utilisation price, which may be calculated from case to case from the pecuniary advantage arising from their use in terms of the costs of material, plant and manufacturing operations. The lowest utilisation price is, therefore, that at the boilers, and the highest, that at the coke ovens. In considering whether a new coke oven plant shall be erected at the iron and steel works or at the colliery, one may estimate the

[19] E. Bertram, *Das Einblasen von Schmelz- und Brennstoffen in die Gestell zone* (The injection of fluxes and fuel into the hearth), Archiv für Eisen hüttenwesen, 1927/28, A.19.

value of blast furnace gas at the steel works in terms of its utilisation value without special capital outlay, and render available double the amount of coke oven gas compared with heating by rich gas, with the same capital outlay. The increased cost is, therefore, the excess freight for coking coal over that for coke, that is for 0·4 tons. In this way it will be found that the coke is 20 to 25 per cent. cheaper at the steel works than coke supplied from outside. Even if blast furnace gas has to be replaced by pulverised fuel firing at the boilers, and the blast furnace gas has, therefore, to be replaced by this value of coal, a saving of 10 to 15 per cent. remains.

The most economical method of producing coke oven gas is, therefore, by coke ovens at the steel works. It is more economical to produce current from coal, or, under favourable conditions, even to cover peak loads from a public supply.

Even if no other opportunities are available for utilising excess of blast furnace gas, the correct policy is to invest capital in order to convert the surplus gas into electric current for long distance transmission. Generally speaking, such dispositions are only possible in the case of large plants which are already established.

The utilisation of blast furnace gas with its many outlets in steel works presents a large number of technical possibilities, but in each case there is only one economic solution of the problem. The heat economist who is best able to solve an individual technical heat problem by physical and chemical means will not be the most successful. Greater success will be enjoyed by the one who is best able to solve a given problem from an economic standpoint. The greater his mastery of the technical foundations of the industry the more easily will he be able to select the best methods.

THE USE OF PRODUCER GAS BY THE ASHANTI GOLDFIELDS CORPORATION

GOLD COAST NATIONAL COMMITTEE

ASHANTI GOLDFIELDS CORPORATION

Paper No. K8

CONTENTS

The conditions in regard to fuel supply in West Africa are somewhat unusual, and up to recent years it has been common practice to burn native timber under steam boilers, usually of the Babcock & Wilcox type; but as the clearings of forest increased, the distance from the fuel supply base to the mine became such that it was clear that the cost of raising steam for power purposes by means of wood fuel was so prohibitive as to necessitate the whole question of power production being reconsidered.

At that time the internal combustion engine had so established itself that the next step was to consider the installation of gas engines and gas producers, using coal as fuel.

At the Ashanti Goldfields Corporation Ltd., Obuasi, West Africa, the first gas plant was installed in the year 1911. It comprised a three-line vertical tandem Westinghouse gas engine, having cylinders 15½ in. and 16½ in. coupled direct to a D.C. generator and capable of developing 300 B.H.P. or 200 kW. continuously when running at 250 R.P.M. The gas producer was of the pressure type supplied by the Horsehay Co., using anthracite coal and capable of supplying sufficient gas to develop 350 B.H.P.

The results justified the partial change-over from steam to gas,

and a further similar set was installed in 1913. At the same time, a gas engine-driven Bellis & Morcom air compressor set, having an output of 2,000 cu. ft. of free air per minute, was ordered and set to work early in the year 1914. The gas producer plant was entirely remodelled, the original producer being dismantled and replaced by three units capable of developing 700 B.H.P. each.

The War intervened, and after the great conflict it was found that the price of anthracite coal had risen to 120/- per ton at the mine, making a total fuel cost for power purposes, including fuel for locomotives used for hauling timber, and for steam raising, as high as 113d. per ton of ore mined in the year ending 1923.

The situation was again reviewed by the directors, and it was felt that the previous decision of installing gas engines had justified itself, but another type of fuel would have to be considered. Their attention was drawn to the results obtained at the Lonely Reef Mine, South Africa, with wood refuse gas producers, as reported in the *Engineer*, August 26, 1922.

It was decided, therefore, to put down an experimental wood refuse producer; and the first Crossley plant, comprising two 350 B.H.P. units complete with tar extractor, scrubbers and accessories, were ordered and installed, and so arranged that they could be connected to the existing gas main in such a manner that two gas engine-driven air compressor units only drew their gas supply from the Crossley wood refuse producers.

The new producers were set to work early in the year 1923, and in August of the same year the author was invited to proceed to Ashanti to inspect and report on the running of this wood refuse plant and the general power equipment of the mine.

After a three weeks' test it was found that the primary coke scrubber or gas cleaner was entirely choked up with tar. It was natural to expect that difficulties would be met with, as different types of wood fuel contain varying values of tar content. After careful consideration of this difficulty it was decided to convert the coke scrubber into a wet scrubber or gas washer, and at the same time to modify the producer from the suction to the pressure gas principle. This modification was effected by installing a motor-driven "Sirocco" booster fan. These arrangements and modifications were completed towards the end of the year 1923, and proved so satisfactory that the directors decided that future installations should be carried out on these lines, and instructions were given for the plant to be extended and brought up to date in

accordance with the experience gained from the foregoing experiments.

One of the most important facts that had to be borne in mind was that the power supply must be available continuously (*i.e.*, 24 hours per day) for 365 days per year, so as to avoid stoppage in the ventilation and pumping out of the mine and ore treatment plant.

With the early type of coal producer plant it was clearly demonstrated that native labour was not sufficiently skilful or attentive to obtain uniform quality of gas. It had to be borne in mind, therefore, that the new wood refuse producer plant must be of a simple character, suitable for operation by native labour with a minimum of European supervision, as the wood refuse is available in different forms, such as waste wood from sawing mine timber, saw mill refuse, and short pieces of timber left over from felling mine shoring timber. Owing to the long length of haul necessary from the base of supply, it was increasingly important that the maximum economy of fuel should be obtained in the producer plant.

It has been very gratifying to all concerned that the Crossley producer plant has substantially met the onerous conditions laid down in respect to this important point, as will be shown by the particulars given below of a fuel test carried out at Ashanti on February 5, 1925, by the author, after the wood refuse producers had been sufficiently extended to enable all the existing gas engines taking their supply from this source.

Trial started, 7-45 a.m. Trial finished, 3-45 p.m.

No. 1 generated 1,169 units		
No. 4 generated 1,034 units	}	Total, 3,130 units.
No. 6 generated 927 units		
Circulating pumps consumed 126.6 units		
Booster fan consumed 28.3 units	}	Total 197.9 units
Tar extractor consumed 43.0 units		

Total fuel consumed, 19,279 lb.

Fuel per unit generated, 6.17 lb.

Fuel per unit sold, 6.58 lb.

Average load on plant, 392 kW.

Average load used by auxiliary plant, 24.7 kW.

Net load sold, 367.3 kW.

Cost per unit generated, 0.44d.

Cost per unit sold, 0.473d.

The results indicate a considerable improvement, even with the old gas engines in operation, the cost of fuel being reduced from 1.9d. per unit generated in 1923 with the anthracite coal producer plant, to 0.44d. per unit generated with the wood refuse plant.

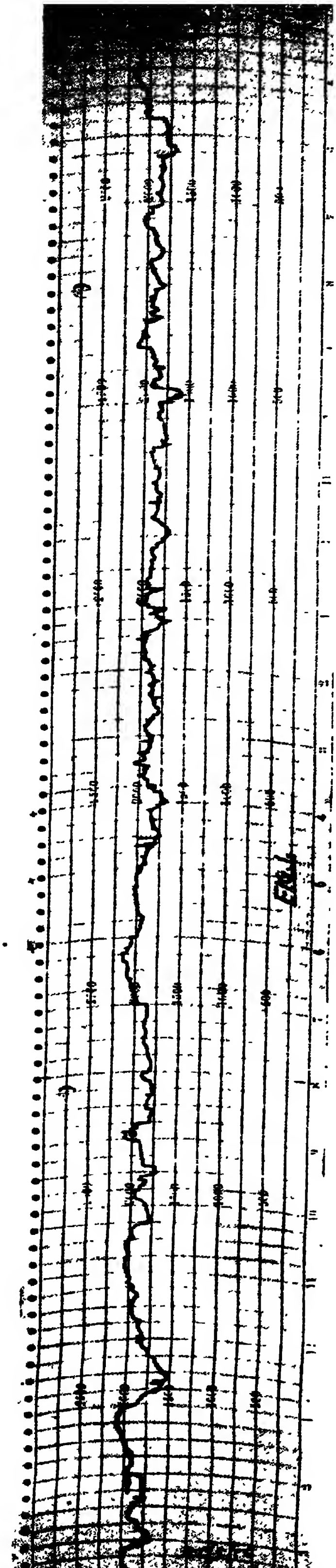
Since the installation of the modern Crossley "Premier" 500 B.H.P. gas engine in 1925, the cost of fuel has been further reduced to 0.29d. per unit (the records being taken over a month's continuous operation), bringing the total fuel cost for power purposes, including fuel for locomotives and for steam, down to the comparatively low figure of about 48d. per ton of ore mined.

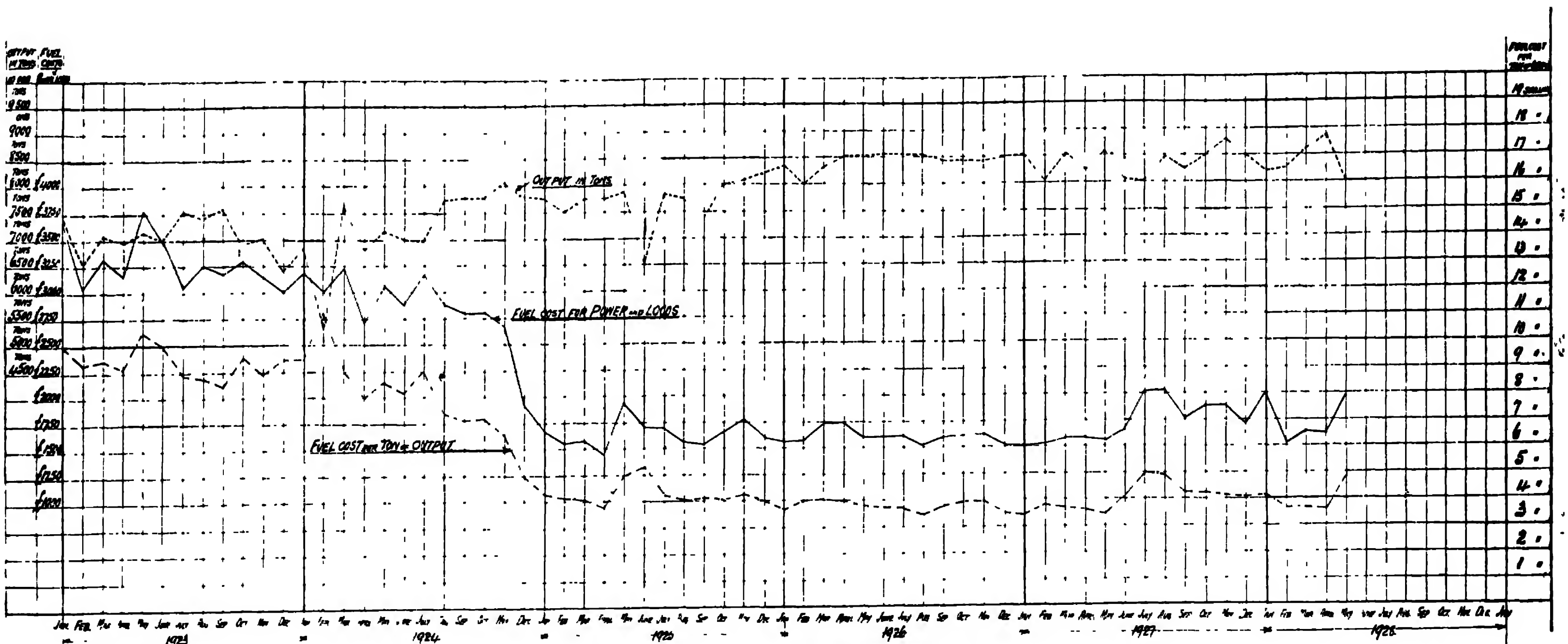
Fig. 1 is the recording ammeter chart, which clearly indicates the relatively steady nature of the load prevailing, which condition is admitted to be most favourable to the economical working of both the gas engines and the wood refuse producers.

Some very interesting comparative particulars are shown in Fig. 2 in graph form, giving the fuel costs and quantity of ore mined per month from January 1923 to May 1928. An analysis of this data shows that the fuel cost per ton of ore mined has been substantially reduced, and that there has been a material improvement in the tonnage of ore, indicating that the modifications carried out to the layout have been satisfactory, and that the type of plant installed has not only proved substantially economical, but efficient and reliable for continuous operation.

The diagram, Fig. 3, shows in section the main features of the Crossley plant, which is capable of gasifying almost any class of wood refuse or mineral fuel. The gas generator or producer is a mild steel cylindrical shell, completely lined—excepting the space occupied by the firegrate—with a thick wall of firebricks, fitted with a superimposed fuel storage hopper and double airlock hopper, through which the fuel is fed into the producer. The firegrate, which supports the fuel bed and through which the air for gasification is distributed to the fuel, comprises a number of cast-iron ring plates carried on cast-iron stools, and arranged in the form of steps. This type of grate is unchokeable and has the special advantage of enabling the operators to view the state of the fire and remove clinker or ash from any region of the grate through the large doors fitted to the side of the producer, without interfering in any way with the continuous working of the plant.

As will be noticed from the diagram, the fuel hopper is of large capacity and has been designed to enable any class of fuel to be fed into the producer without risk of admitting air. Normally,





A. G. C FUEL COSTS FOR POWER AND LOCOS

— FIGURE 2 —

the lower end of the feeding hopper is sealed by a cast-iron mushroom-shaped valve kept tightly in position on its seating by a series of levers connected to the weighted operating handle, and, in addition to this, a counter-balance cover is fitted to the top of the container, thus ensuring a total airlock.

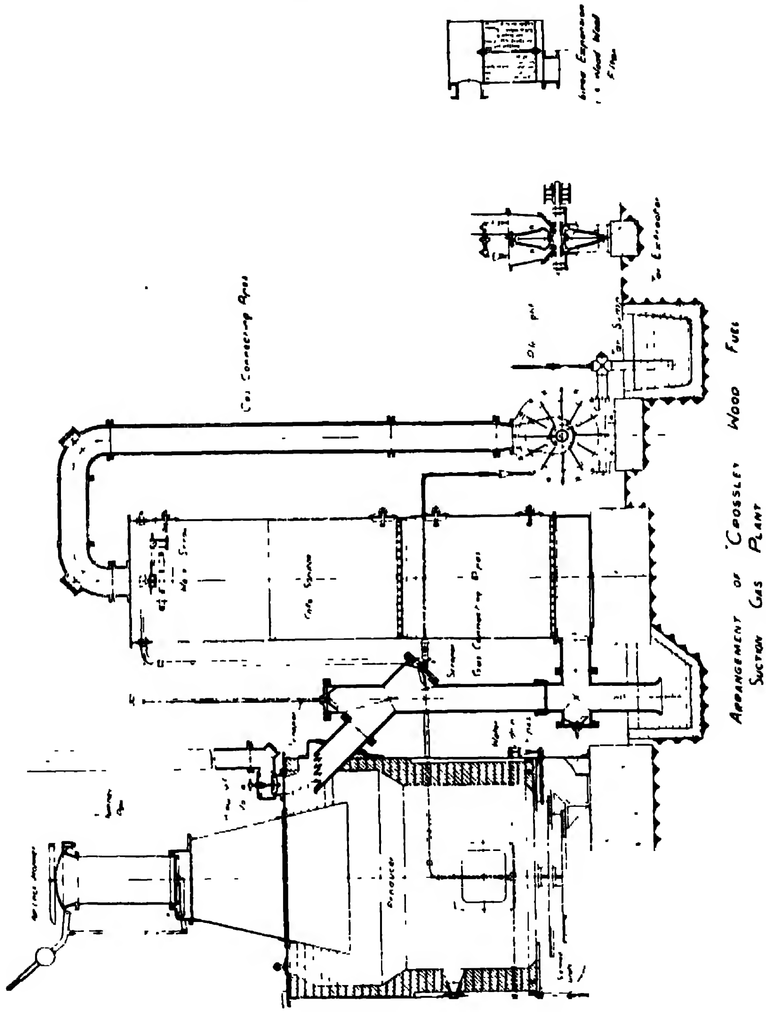


Fig. 3.

When feeding the producer the top cover is pushed to one side, the fuel placed into the container, and the cover replaced again. By simply lifting the hand-operating lever the tower valve drops

clear of the container and allows the fuel to fall into the storage hopper, whence it falls by gravity into the gas container proper. At the same time the operating lever engages with another lever on the top cover and holds it securely in "closed" position.

The pipes which convey the hot gas from the producer to the cooling and cleaning plant are fitted with a special form of scraper whereby tarry deposits can be removed without interfering with the continuous operation of the plant.

The gas washer is a vertical cylindrical vessel filled with wooden bars, placed one above the other in the form of a grillage. The gas passes upwards through this grillage and comes in direct contact with streams of water distributed by a series of splash plates and water supply pipes, placed in the top of the cooler. The gas leaves the cooler at a temperature suitable for the extraction of tarry products.

For power purposes the gas must, of necessity, be thoroughly cleaned of all tarry volatile matter which would cause sticking of the engine pistons and valves. This is accomplished by passing the cooled gas through a mechanically-driven centrifugal tar extractor, which is efficacious in condensing and coagulating the tarry gases and throwing these residuals on to the side of the casing, whence they drain into the tar collecting sump.

For the final cleaning and drying operation the gas is passed through layers of sawdust or wood wool carried on trays in cylindrical or rectangular vessels.

A general arrangement plan, showing the gas plant units up to date, is given in Fig. 4. It will be seen that there are six producers or generators and coolers, coupled together to work either in series or parallel with three motor-driven tar extractors. The gas is drawn from the plant and delivered to the final dryers, which were already in existence (having been used previously in connection with the anthracite gas plant) through the medium of three motor-driven "Sirocco" centrifugal gas boosters supplied by Messrs. Davidson & Co. Ltd., of Belfast. Each gas producer has a rated output of 350 B.H.P. when using ordinary saw mill refuse, and 450 B.H.P. with logs or cut timber, therefore the total capacity of the plant, including one producer as standby, is approximately 2,250 B.H.P.

The policy of gradually displacing the steam sets for all power purposes, and the very successful results obtained from the first

two 350 B.H.P. wood refuse producers, set to work in 1923, led to the decision to order two other exactly similar producers, Nos. 3 and 4, in July and November, 1924, and again in 1927 Nos. 5 and 6 were ordered. All six producers are identical and interchangeable. This reduces the amount of spare gear to be carried, an all-important item in connection with plant operating abroad, as well as simplifying the working of the producers by unskilled native labour. Concurrently with the ordering of Nos. 3 and 4 producers, an order was placed for a Crossley "Premier"

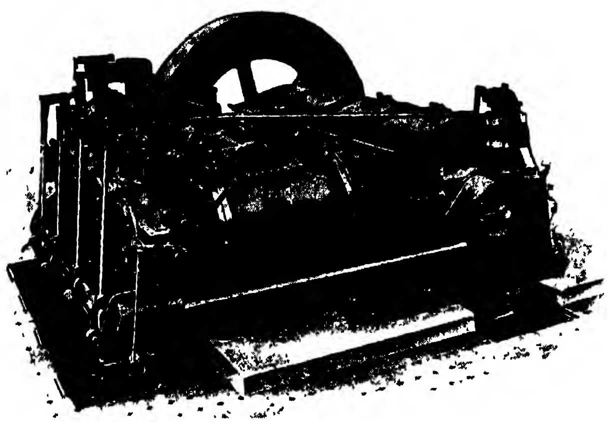


Fig. 5.

four-cylinder gas engine, direct coupled to a Mather & Platt D.C. generator, capable of developing 500 B.H.P. continuously, and having an overload capacity of 20 per cent. for short periods. This set proved so economical and reliable under continuous operation that another set was ordered in October 1927.

In connection with the modernising of the power plant, the company's engineers gave special consideration to the labour conditions prevailing at the mine, and specified that the following essentials should receive very careful consideration when making a decision as to the design of engine installed.

(*a*) Reliability of continuous operation.
(*b*) Simplicity of construction.
(*c*) Ease of dismantling and maintenance.
(*d*) Interchangeability of parts.

(*e*) That important but often neglected facility, ease of cleaning the water spaces of the combustion chambers, valve pockets and cylinder liners.

The two new gas engines installed in the central power house were supplied by the Premier Gas Engine Co. Ltd., Sandiacre, and are of their well-known horizontal multi-cylinder type. Each engine is arranged with four cylinders, each of 20 in. bore, with a stroke of 28 in., and running at a speed of 190 R.P.M. As already mentioned, they are directly connected to Mather & Platt D.C. generators, the combined sets each being capable of developing 335 kW. continuously, and having an overload capacity of 20 per cent. Fig. 5 shows the general appearance of these engines.

In conclusion, it might not be out of place to state that the total number of units generated by the modernised power plant at the Ashanti mine from May 1927 to May 1928 was about 4,000,000, *the average fuel costs working out at 0.29d. per unit generated.* Although the fuel costs have been reduced to the excellent figure given above, full advantage cannot yet be taken of the improvements made to the gas producing plant until the second modern 500 B.H.P. gas engine has been set to work.

ZUSAMMENFASSUNG

In Westafrika herrschen in Bezug auf die Brennstoffversorgung eher ungewöhnliche Verhältnisse. Bis vor kurzem war es allgemein üblich, in den Dampfkesseln einheimisches Holz zu verfeuern. Die Wälder wurden abgeholzt, und das Holz musste aus zunehmenden Entfernungen hergeschafft werden. Dies benötigte eine erneute Betrachtung der ganzen Frage der Krafterzeugung.

Der Bericht beschreibt, wie die Ashanti Goldfields Corporation das Problem seit 1911 durch Verwendung von Gasmotoren zu losen suchte, welche Schwierigkeiten dabei zu überwinden waren und welche Erfahrungen gemacht wurden

INDUSTRIAL HEATING BY SOLID, LIQUID AND GASEOUS FUELS

TECHNICAL COMMITTEE, FUEL CONFERENCE, 1928

SIR ROBERT HADFIELD, BT., F.R.S., AND R. J. SARJANT

Paper No. K9

CONTENTS

SECTION I—SOME ASPECTS OF THE RELATIVE VALUES OF FUELS FOR INDUSTRIAL HEATING

Whilst it is practicable, within the range of the art, to use any fuel for any given operation, the choice of the fuel is limited by its availability, economic value, and those other practical factors of widely differing character, classified together for convenience under the term adaptability.

Coal and its derivatives -producer gas, town's gas and coke—are the fuels which must always occupy in this country the dominant position as regards availability and economic value. It is to be hoped that the time is not far distant when the commercial production on a wide scale of oil from coal will be practicable. The incidence of the coal dispute during 1926 gave an opportunity for the demonstration of the advantages of oil fuel from petroleum sources, which might not otherwise of themselves have offered a sufficiently attractive inducement to industrialists to change their methods of heating.

Comparing the relative costs of the native coal and imported oil, the trend is now operating to the disadvantage of oil, as indicated in Table I. The values given for the coal prices are the Index Numbers of Wholesale Coal Prices, compiled by the Board of Trade.[1] Those of the relative costs of oil are based on prices of oil delivered in Sheffield for industrial purposes as compared with a coal of 12,500 B.Th U. per lb., costing 12s. per ton (2,240 lb.) at the 1913 index figure of 100. Certain conflicting tendencies render the ratios given only roughly comparative, namely, in some districts, deterioration of seams, in others, improvement of quality consequent upon the development of screening and washing plant.

TABLE I.

Year.	Average B.O.T. Index Nos. of Wholesale Coal Prices (1913 Index = 100)	Relative cost of oil fuel for same thermal value.
1922	171·7	418
1923	179·3	411
1924	172·3	441
1925	146·2	466
1926 Jan to April	141·2	466
1927	—	461

In regard to the relative trend of costs of gaseous fuels, the issue has been complicated by a number of factors. Thus, whilst the general trend has followed that of the coal from which it is produced, in those cases, for example, town's gas, in which the costs of production have been associated with heavy distribution charges, there has been a lag in the trend to the disadvantage of this fuel.

These movements with regard to the cost of the therm may be offset by the development of technical practice, which tends to enhance the value of the adaptability factor. Accordingly, it is desirable to review this aspect in some detail.

OIL FUEL

Thermal Efficiency. The main advantage of oil fuel in this respect lies in its high flame intensity, ranging between 1,500° and 2,000°C., according to the excess air and heat loss from the flame associated with its size, as compared with 1,400° to 1,750°C. for town's gas. Comparable tests undertaken by the Fuel Section of the Research Department of the authors' firm have shown the following to be typical of a heat treatment operation on steel at a temperature of

[1] See article by F. C. Evans, "Britain's Fuel Problems," p. 237.

760°C. The conditions were kept identical as to furnace and heating arrangements, the rate of heat supply being five therms per hour. A town's gas of 500 B.Th.U. per cu. ft. gave a thermal efficiency of 20·5 per cent; a fuel oil of 19,000 B.Th.U. per lb. gave 23·5 per cent.

For higher temperatures of operation wider differences have been reported in comparison with solid fuel. Thus in the kiln firing of silica bricks to 1,500°C., Mr. Frank West[2] reports a consumption of 644 lb. of crude oil (19,400 B.Th.U. per lb.) per 1,000 squares ($9 \times 4\frac{1}{2} \times 3$ in.) as against 1,093 lb. of good coal (13,700 B.Th.U. per lb.). The thermal efficiencies approximated on the data given were respectively 37·6 per cent. and 31·4 per cent. for oil and coal respectively, indicating a 20 per cent. advantage for oil fuel.

Flexibility. The high intensity of heating with oil fuel in conjunction with ready control, within limits, enables the maximum rate of heating to be obtained of which the refractories permit, as, for example, in lighting up in day-shift working (see later for rates of heating of refractories). An important field of utility involving this advantage is "in and out" furnaces for small forgings, drop stamping and rivet heating. In certain instances in which oil has replaced coke its continued use has only been justified on the ground that an enhanced rate of output became possible. Coke fired furnaces for such operations still have, and rightly so, a strong hold where the design of the furnace is of superior type, and the output demand is in convenient relationship with the capacity of the furnace.[3] The reduction of time in operating biscuit ovens on oil in the ceramic industry, has proved the dominant factor in retaining its use.

Adaptability. Under this heading is comprised those items such as floor space required for the furnace and fuel storage and supply, labour requirements, regularity of fuel supply, and suitability for intermittent operation, in regard to which any form of fluid fuel, including powdered coal on the central system, has an advantage over solid fuel. The value of such conditions may entirely, on occasion, outweigh that of the fuel cost.

Disabilities. On the other side of the balance sheet must be reckoned certain disabilities of oil fuel, associated with the high intensity of the flame. Of the two effects most pronounced the first is the difficulty of obtaining uniform heating, and the second the severe erosion of refractories. In regard to the former there are burners on the market which give reasonable satisfaction in service,

"Iron and Coal Trades Review," March 16, 1928, p. 385.
See R. W. Peck, "The Drop Forger," Vol. 5, No. 4, February 1926, p.233.

though, naturally, any complication of design to give flexibility is associated with a multiplication of parts liable to become burnt out or sooted up. The resultant increase of maintenance charge is added to that other item, arising from the second effect, the maintenance of refractories.

The problem of the refractories may be solved in several ways. Carborundum is one remedy, though high in first cost. Sillimanite is suitable, provided spalling tendencies are safeguarded either by using the refractory with an open structure, or carefully controlling the rate of heating and cooling Grog firebricks, high in alumina, and patchings of silica-fireclay millings are also practicable

In extensive oil burning equipment there is further need for adequate control of oil viscosity and filtration Oil tight joints are not readily made, a point to be watched where cleanliness is essential

GASEOUS FUELS

Producer gas constitutes a form of heating which has suffered an adverse trend in recent years due to the advent of day-shift working only Separate producer units carry a heavy standby charge for lighting up There is also a gasification loss of 15 to 25 per cent., according to the type of plant. Nevertheless it still remains the most satisfactory form of heating large furnace batteries in continuous operation under conditions permitting adequate recuperative or regenerative practice The mechanical producer is coming into increasing use in such directions The cost of the therm delivered to the furnace at the present time varies in the range 1·3 to 2 pence, inclusive of all charges, according to the size and output of the gasification plant For small units the built-in producer is the most efficient means of application. The so-called semi-gas producer does not, in our experience, fall into this class of heating, for it does not admit of high proportions of secondary air to be used. Immediately after firing as much as 50 per cent. of the air used may be of secondary origin, according to the relation of the thickness of the fuel bed to the rate of combustion per unit area af fuel bed But as the volatiles in the distillation zone of the fuel bed burn off, the amount of secondary air which may be used falls off asymptotically to such a low value that the average proportion of secondary air used is only about 10 per cent. of the total.

Town's gas carries a much higher therm cost at the furnace, but for the smaller types of industrial heating operations covering a wide range of service in repetition work, in which the relation of

the number of articles handled to their total heat capacity is high, it has an enhanced value as regards those other factors already alluded to in reference to oil firing. Further, it has an important advantage as regards uniformity of heating, and its applicability to surface combustion methods admits of high radiation effectiveness.

By the courtesy of a number of the largest gas undertakings in the country, it is possible to indicate in a broad manner the extent to which its use is being adapted to industrial needs. Taking seven of the largest organisations in industrial districts, the average consumption devoted to industrial heating is about 15 per cent. of the total make. From the years 1924 to 1927 the consumption for industrial heating increased each year by, roughly, 1 per cent. of the whole total. The largest industrial load was 47·9 per cent. of the total for the undertaking. For the whole country, however, it is doubtful if the proportion devoted solely to industrial heating exceeds 10 per cent.

On the basis of the following figures (Table II) of coal carbonised each year, and gas made by authorised undertakings in Great Britain, and on that of an average calorific value of 475 B.Th.U. per cu. ft., it is evident that the town's gas utilised for industrial heating is of the order of 140,000,000 therms.*

TABLE II

COAL CARBONISED AND GAS MADE BY AUTHORISED UNDERTAKINGS IN GREAT BRITAIN

(From Part I of the Board of Trade Return)

Year	Coal carbonised—tons	Gas made—millions cu. ft.
1924	17,329,180	275,226
1925	17,031,172	283,818
1927	17,703,593	297,697

The future possible industrial demand would no doubt benefit from a modification of the method of charging for the gas on the lines of the so-called "three-part" system, which has come to the fore of late, since that method permits of a more equable partition of the distribution costs as between large and small consumers, and the offer of gaseous fuel in large quantities at rates more nearly competitive with other fuels. The same result is attained to some degree by the system of lowering the rates for all consumptions beyond certain arbitrarily chosen limits, which method bears,

*A *Therm* represents 100,000 B.Th.U. Unless otherwise stated in this contribution 1 *ton* = 2,240 lbs. and 1 *cwt.* = 112 lbs.

however, only a partial resemblance to the more logical one of a sliding scale.

Town's gas is used for industrial heating in about 3,000 distinct trades, in each of which it is employed, on the average, for seven processes. The publications of the British Commercial Gas Association[4] are fertile in illustrations of these. A very large number of small furnaces of low thermal capacity are in use for operations of short intermittent character, in regard to which the "lighting up" gas consumption, necessary to bring the furnace to its working temperature, represents a very appreciable proportion of the total gas required for the heating cycle. The development of the self-contained recuperative furnace with metallic air preheating tubes, operating on the counter-current principle, reduces the "period of advantage" of the simple oven type. In addition the use of insulation materials, hitherto largely ignored for the same reason, is now being adopted. High thermal efficiencies have been obtained with the reversing regenerator type, for example, 55 per cent of the net calorific value for an operation at 1,000°C.[5]

Prevention of Scaling

It is known that the term "reducing atmosphere" in flame furnaces is a misnomer,[6] and that to obtain entire protection against scaling an atmosphere of combustible gas must be present. Successful operation is obtained by heating in a muffle containing either an atmosphere of town's gas or producer gas and arranging for mechanical discharge of the material through a water seal.

The development of modern heat resisting steels has made possible the conveyor and the metallic muffle for operation at temperatures up to 1,000° or 1,050°C. For those operations of small parts in which it is desired to protect the charge from the scaling effect of the atmosphere, and for which the gas or oil furnace offers the best heating medium, the use of boxes made of the same material, mechanically charged and discharged, is desirable. The best possible combination for furnaces utilising fluid fuels at the moderate temperatures mostly in use have proved to be well lagged types with carborundum hearths, and an adequate recuperative or regenerative system, preferably using mechanical draught.

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[4] "A Thousand and One Uses for Gas." Bulletin of the B C G A

[5] H. Hartley, "Fuel Economy Review," 1926, p 49.

[6] "Furnace Heating" by R J Sarjant, p. 78
Papers by Cobb and others, Journal of the Society of Chemical Industry, 1927.

Gas Consumption

Subject to the limitation of variation due to local conditions, such as character of the charge, rate of heating and temperature gradients permissible, the following may be regarded as representative of the heat required in town's gas heating in a list of typical industrial heating operations:—

TABLE III.

HEAT REQUIRED AS TOWN'S GAS IN *THERMS PER TON* FOR TYPICAL INDUSTRIAL HEATING OPERATIONS

Operation.	Ordinary oven furnace	Recuperative or regenerative oven furnace.
Hardening ...	25–35	15–20
Tempering ...	20–25	10–15
Annealing ..	20 35	15–20
Normalising . .	20–25	12-17
Rivet heating ...	55	
Billet heating.—		
950°C. ..	30–35	15–20
1250°C .	35-40	20–25
Forging .	34-75	20–30
Plate heating .	30-40	20-25

Use of Oxygen to obtain High Temperatures with Gaseous Fuels

The future possible utilisation of oxygen in industrial heating has received some attention,[7] but the present cost of oxygen is prohibitive for commercial development. It is not likely that oxygen enrichment under these conditions will offer any advantages in normal operations, as the following statement shows. On theoretical grounds the same increment of flame intensity which is obtained by oxygen enrichment may readily be obtained by preheating of the air. The measure of this increment may be indicated from an actual comparative experiment. The combustion of town's gas of 500 B.Th.U. per cu. ft. was enriched with 5 per cent. of oxygen, based on the total volume of the supporter of combustion, and the increase in the working temperature of the furnace observed. The temperature without oxygen was 1,570°C. and with oxygen

[7] "Industrial Oxygen" by T. Campbell Finlayson, reprinted from Trans. Inst. Chem. Eng. 1923. (Containing bibliography complete up to that date of scientific and patent literature on "Oxygen.")

"Use of Oxygenated Air in Metallurgical Operation." Symposium of American Inst. Min. Met. Eng. February, 1924.

Report of the Committee for the application of Oxygen or Oxygenated Air, by F. W Davies, Serial No. 2502, Reports of Investigations, U.S.A. Bureau of Mines, July, 1923.

it was 1,630°C. under exactly comparable conditions of rate of gas flow, load, etc. The difference in theoretical intensity calculated from the composition of the gas was 45°C.

SOLID FUEL

The disadvantages of solid fuel firing include a large number of points, not the least of which are ash troubles and imperfect combustion conditions associated with the production of smoke. But since every fuel bed is, in a sense, a gas producer, it cannot be maintained that solid fuel firing is incapable of improvement beyond its present stage of development. In the course of a few inches, it has the same sequence of oxidation, reduction and distillation zones, producing nearly 30 per cent. of volatile combustible matter immediately above the bed, and, in the absence of channels, a complete utilisation of the oxygen. For the bulk of intermittent metallurgical furnaces no successful means of maintaining such a small, even fuel bed mechanically has yet been found. Small mechanical stokers for such purposes have been adapted, but not yet to any appreciable extent. The main difficulties to be overcome are economic, the provision of the necessary mechanical gear to feed the fuel bed and discharge the ashes, at a cost in keeping with the maintenance and capital charges which such a small unit can bear. Such a means of firing, combined with adequate exchange of sensible heat of the waste gases into the primary air used for combustion, would give the maximum utilisation of heat energy in the furnace.

The advent of heat-resisting steel, capable of withstanding oxidation up to temperatures exceeding 1,000°C., combined with great strength at high temperatures, makes practicable this last step so far as regards material. Such steels are available in various fabricated forms, such as machined castings, forgings, plates, sheet, rod, wire and tubes.

In addition, a definite resistance to the action of sulphur can be obtained, which is not the case with alloys containing high percentages of nickel. Already the successful adaptation of mechanical stoking has been made to marine boiler practice with the help of such materials.

The clinkering inevitably associated with the preheating of primary air is not serious with moderate preheats on small grates at high combustion rates. This is evident by reference to the performance of the forge furnaces, reported in the section on heat recuperation. In any case, the more severe conditions are not insuperable if a

type of mechanical grate capable of breaking up and removing the clinker be provided.

Powdered fuel continues to make headway in reheating furnaces, soaking pits, reverberatory furnaces, plate heating and annealing. It has made little progress as yet in the more specialised low temperature field, where the high intensity of the flame and the contamination of the product with fused ash constitute serious disabilities. Development is, however, expected to follow the refinements of burner design, admitting of the use of smaller combustion chambers. Its main advantage lies in the utility of low grade fuels offering a low cost per therm. A further advance lies in the method of partial gasification at the burner, and the utilisation of preheated air.

The semi-coke produced by low temperature carbonisation has not yet offered serious competition in industrial practice, and the possible use of the inferior types of char in pulverised form still remains, in this country of good fuels, a problem of the future. We look to the domestic field as the more suitable direction in which the utilisation of semi-coke should make progress

COAL CONSUMPTION

Since 1913 the world's coal production has remained stationary, according to figures compiled by the National Bank of Commerce in New York, thus:—

TABLE IV

TOTAL WORLD'S PRODUCTION OF COAL

Year	
1926	1,355 million metric tons (1,000 Kg.)
1925	1,361 ,, ,, ,,
1913	1,341 ,, ,, ,,
1886	400 ,, ,, ,,

The rate of output prior to 1913 was increased at the rate of 4 per cent. per annum. The change since 1913 is attributed to three main factors:—

(*a*) Competition of oil fuel,
(*b*) Increase in hydro-electric power,
(*c*) Improved methods of the use of coal itself which give more units of work per unit of coal.

To take the comparison of the production of electrical power, in regard to which reliable statistics are available; prior to 1913 there were many stations using 3 to 5 lb. of fuel per kWh. generated.

In the report of the Electricity Commissioners for the year ended March 31, 1925, the average of all stations generating over 1,000,000 units yearly had dropped to 2·5 lb., and the best recorded result was 1·51 lb. It has not been possible to indicate a parallel in industrial heating practice though, doubtless, improvements obtainable in the best of modern furnaces are commensurable.

Coal Consumption in Iron and Steel Works

The iron and steel industry constitutes the largest consumer of coal for industrial heating, as is indicated by the following statistics, kindly supplied by Mr. E. C. Evans, the Fuel Officer of the National Federation of Iron and Steel Manufacturers.

TABLE V.

COAL CONSUMED IN IRON AND STEEL WORKS

	1924 Tons	1925 Tons.	1927 (estimated). Tons.
Pig iron	7,307,400	6,261,700	7,293,600
Coal equivalent of coal and coke used	14,658,929	12,485,700	13,293,000
Coal used for finished iron and steel (including boiler and furnace fuel but excluding coke for pig iron)	10,340,000	9,260,000	11,700,000
Finished steel	6,773,500	6,502,800	7,625,000
„ wrought iron . . .	456,100	341,400	305,000
	7,229,600	6,844,200	7,930,000

The following are the authors' estimates for soaking pits, reheating and forge furnace practice. They represent fair averages of good practice, the actual attainable values depending primarily on the load:—

TABLE VI.

FUEL USED PER TON OF MATERIAL CHARGED

(In terms of a standard fuel of about 12,300 B.Th.U. per lb.)

(*a*) Soaking pits ... ... $1\frac{1}{2}$ to 4 cwt. per ton

(*b*) Reheating furnaces:—

- (i) Heavy sections, blooms, etc , over 5 cwt. ... $1\frac{3}{4}$ to 5 cwt. per ton
- (ii) Light „ „ under 5 cwt... 2 to 10 „ „ „

(*c*) Forge furnaces:—

- (i) Heavy sections, blooms, etc., over 5 cwt. ... 3 to 8 cwt. per ton
- (ii) Light „ „ under 5 cwt... 2 to 10 „ „ „

Mr. E. C. Evans (private communication) cites the following actual coal consumptions over extended periods at typical works:—

TABLE VII.

	Cwt. per ton of material charged. Average.	Minimum.
Soakers and slab mill together	2·5	2·2
Plate mill	4·0	3·1
Plate mill	4·5	4·2
Sheet mill	7·2	6·0
24 in. Section mill	3·0	2·1
18 „ „ „ with continuous furnace ...	3·1	2·56
10 „ „ „ „ „ „ ...	3·1	2·9
Annealing (wire) ... gross (plus pots) ...	wide variation	3·0
net		1·5

With regard to this last item, the best recorded experience that has been brought to the authors' notice was obtained in a gas-fired recuperative pot furnace of rotary type.[8]

As a more exact indication of the operation of the load variations referred to in connection with Table VI., the following statistics of fuel consumptions are cited of a coal of average heating value of 12,000 B.Th.U. per lb. used in billet reheating furnaces in a rolling mill, operating mostly on special alloy steels. The coal consumptions represent the total coal used on the plant. A datum line of average performance may be plotted from these values of fuel ratio against

TABLE VIII.

FUEL CONSUMPTION—OUTPUT RELATIONS IN COAL-FIRED INTERMITTENT REHEATING FURNACES

Hearth area / Billet size.	80½ sq ft / 60 to 80 lb	101½ sq. ft. / 100 to 250 lb.	
Fuel ratio. Cwt./ton.	Output. Cwt. per hr.	Fuel ratio Cwt./ton.	Output. Cwt. per hr
(*a*) Varied types of steel.		(*b*) Steel type, requiring slow heating	
9·6	5	10·7	4·5
8·0		9·9	5
6·8		8·5	6
5·9		7·0	8
5·2		6·6	9
4·65	10	(*c*) Separate type of steel.	
4·0	12	5·5	4·5
		5·0	5
		4·0	7
		3·8	8
		3·9	9

Alloy steels of type similar to those classified in series (*a*) and (*c*) have given, in a continuous type of furnace in the same works, a fuel ratio as low as 2 cwt./ton.

[8] See "Furnace Heating" *ibid.* p. 74.

output. The constant compilation and study of the type of record shown has been the practice in the works of the authors' company for nearly twelve years.

SECTION II FACTORS AFFECTING FUEL CONSUMPTION

Continuous working with a uniform load, suitably adapted to the size and type of furnace, is an essential requirement for fuel economy. The exigencies of the general shop problem frequently exclude such desirable conditions, and, moreover, there is the incidence of change in the character of the shop operations, which it is not always possible to foresee. Thus the capacity of the furnace must be adaptable to the possible full range of variation of character of material to be heated. This aspect of the heat economy problem is the most difficult to surmount It involves consideration of the wider problem of general works management, and is responsible more than any other factor for the relative low thermal efficiencies of the order only of 12 per cent. of the heat input (taking an overall average for industrial practice), which are so frequently deplored

Even so, and granted that the load factor has been favourably fixed, it is in regard to the definition of the geometrical factor that the technique of furnace construction possesses the attributes of an art All the fundamental laws governing the heat flow in the furnace involve this factor, expressed, for example, as the mean hydraulic depth of the gaseous streams in the convection laws. If the whole problem were as readily solved as that for confined ducts of such simple form as a tube, more definite computation of furnace problems would be possible.

Relation Between Heating Surface and Thermal Efficiency

In Fig. 1, adapted from "Britain's Fuel Problems," p 263, are collected a number of results of comparisons of thermal efficiencies (defined as the ratio of the sensible heat utilised in the material to be heated, to the heat supplied to the furnace), with the degree of utilisation of the heating surface. The numbers placed against the different curves are references noted in the key, and in Tables IX. and X. of data of test results. Apart from variations due to differences in the types of the furnaces, and their manifold characters, it is remarkable how definite is the general relation between thermal efficiency and the degree of utilisation of the heating surface. Careful study of the data given in Table IX. which is a compilation of furnace records reported by W. P. Chandler,[9] in regard to the position of the points 9 to 14 in Fig. 1 will reveal the following points of interest.

[9] American Iron and Steel Institute, 1922

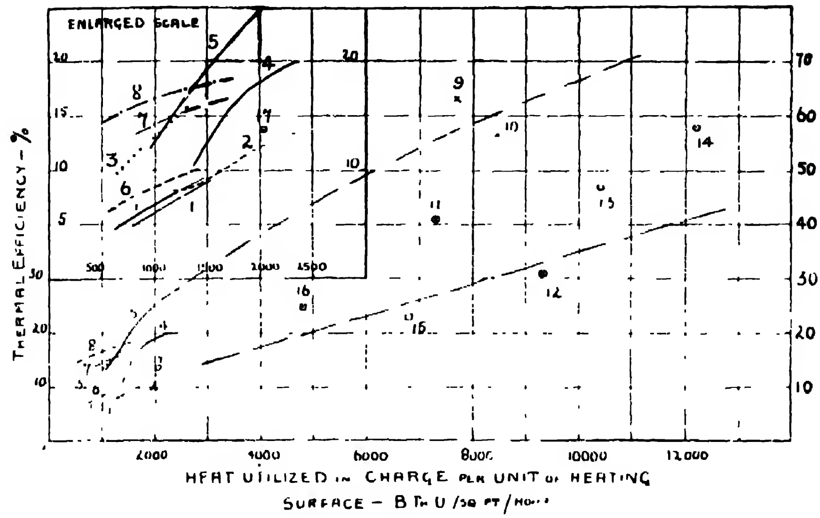


Fig 1

RELATION BETWEEN THERMAL EFFICIENCY AND HEAT UTILISED (B Th U) per sq ft of HEATING SURFACE per hour

CURVE No —(1) and (2) Forge furnaces coal-fired, billets 60-80 lb (3) Forge furnaces, coal-fired, billets 100-250 lb with some heat recovery (4) Reheating furnaces, regenerative producer gas fired (5) Reheating furnaces, open flame gas-fired (6) Muffle furnaces, gas-fired. (7) Heating furnaces, regenerative producer gas-fired, intermittent, temperature 1,000 C (8) Heating furnaces, regenerative producer gas-fired, intermittent temperature 800-850 °C

POINTS – (9) to (14) recuperative and regenerative gas-fired (Table IX), see Chandler, American Iron and Steel Institute, 1922 (15) Recuperative, continuous, producer gas-fired, ingot heating (Table X) (16) Coal-fired continuous billet heating (Table X) (17) Small "in and out" coal-fired forge furnace

TABLE IX

SUMMARY OF TEST DATA ON REHEATING FURNACE TESTS (CHANDLER)

tallic (cast

in ft (length breadth) 32 36 18 36 × 18

Rate of outpu (lb. per sq ft hearth per hour)

Weight of I

at absorbed by steel

water from hydrogen aste gases (dry) 22·39 22·08 26·24 24·7

16·48 14·54

at returned by recuperation or re ration (per cent of total heat)

TABLE X.

COMPARISON OF RECUPERATIVE GAS-FIRED AND COAL-FIRED CONTINUOUS REHEATING FURNACES

	Producer gas-fired recuperative.	Coal-fired.
Reference No. in Fig. 1	15	16
Output—tonnage	12½	2
Class of material	square ingots. 11 in.	small billets.
Final temp. of material—°C.	1,300	1,100
Fuel consumption—cwt. per ton ...	2·58	2·0
B.Th.U. per ton 10^3	326	292
Hearth area—sq. ft.	621	100
Ratio of output to hearth area—lb. per sq. ft. per hour	45	44·8
Heat supply—B.Th.U per sq ft. hearth area per sec.	20·4	16·2
Heat utilised do. do.	4·7	4·0
Heat balance:—	per cent	per cent
Useful heat in material	23·0	24·7
Sensible and latent heat in waste gases	22·4	30·4
Gas generation loss	15·0	
Unburnt combustible in ashes ..	0·8 —	2·8 —
Unburnt gases	1·8 2·6	4·5 7·3
Radiation, convection, conduction through settings, and other losses .	37·0	37·6
	100·0	100·0

In the recuperative furnaces, Nos. 9, 10, 13 and 14, the throughput of the lighter sections is associated with the lower thermal efficiencies and the higher losses, the geometrical factor, defined by the size of the material heated, being in this case the circumstances governing the differences recorded. Further, the distinct advantage of the continuous recuperative type is not due to differences in the type of heat recovery. Actually, the proportions of heat returned to the furnaces by the recuperators are relatively low compared with the regenerator recovery of the non-continuous furnace. The main disadvantage of the latter is the high radiation loss associated with whole bulk of the furnace structure requiring to be maintained at the working temperature, whereas with the continuous furnace a gradient of temperature occurs, and only the discharging end of the furnace is at the finishing temperature.

Again, in a comparison of a small coal-fired reheating furnace (No. 16), and a recuperative gas-fired furnace (No. 15), alluded to in Table X., it will be noted that what the gas-fired furnace loses in gas generation loss it recovers in improved combustion and heat recuperation, but from the relative position of the point 15, in comparison with, say, Nos. 16, 9, 10, 11, 13 and 14, one would conclude that it has some relative defect in lagging, recuperator efficiency or geometrical feature, such as height of crown, passage

of the hot gases between ingots, door leakages, etc., which disadvantage is not present in the other furnaces. The furnaces chosen represent a comparatively simple geometrical problem. It would not be expected that such results would fall in line with data on annealing furnaces, taking a charge of complicated castings. Again, improvements in insulation and recuperation, avoidance of heat loss due to air in leakages and improper combustion, would of themselves tend to throw the points off the general curve.

From these remarks one would derive the conclusion that an effective means of improving thermal efficiency in batch type furnaces is the adoption of the rotary hearth, since it brings about an enhanced utilisation of heating surface.

THE CRITICAL RATE OF HEATING

An almost obvious feature of furnace control, which is, however, frequently overlooked in practice, is that there is for any given load, in either furnace or kiln, a critical rate of heating which gives the minimum values for the total heat losses in the heat balance. If the rate of heating is below this particular speed, the external losses in radiation and condition are excessive Overdriving produces excessive loss in the sensible heat in the waste gases. The point of balance can only be obtained in practice by an actual succession of runs, for there must be an ideal rate corresponding to each type of charge. In a kiln or batch annealing furnace, the surface-weight factor is the criterion; in heating a heavy forging, or annealing box, it is the section and heat diffusivity of the material of the charge (governed in the latter instance by the insulating influence of the surfaces). In a continuous furnace the criterion is the relation which the heat absorbing capacity of the charge bears to the available heating surface.

The influence of the rate of driving is the only explanation of the results recorded in Table XI., which gives the relation between the calorific value of the gas and the thermal efficiencies obtained in a shop of heat treatment furnaces operating on town's gas at a time of stress, when it became imperative for the undertaking supplying gas at a lower calorific value. The records all apply to the same load, that is to the same rate of heat absorption in the material, which amounts to 8,800 therms in each test period of a week.

The ideal rates are more readily obtained by the utilisation of liquid or gaseous fuels, and in general, though especially so in the case of solid fuel, their desirability provides an argument for mechanical

TABLE XI

RELATION OF THE THERMAL EFFICIENCY TO THE CALORIFIC VALUE OF TOWN'S GAS FOR A BATTERY OF HEAT TREATMENT FURNACES AT APPROXIMATELY CONSTANT LOAD

Thermal efficiency %	Calorific value (net) of the gas. (B Th U. per cu. ft at 60°F. and 30 in Mercury)
13 75	390
14·00	405
13·75	415
13·35	450
12·80	456
11 60	473

draught control These statements indicate that a pyrometric installation, measuring the temperature either in the furnace chamber or at the outlet of the waste gases, is an essential part of a furnace unit, to enable the time-temperature relation to be observed. Such remarks apply with special force to batch furnaces The use of the pyrometer is needed to save fuel as well as for the technical control of the product.

HEAT SAVING BY RECUPERATION AND REGENERATION

A well recognised feature of recuperation, the value of which, though not readily assessed, is nevertheless definite, is the improve ment of temperature gradient attainable in the heating chamber, due to the increase of flame intensity resulting from the preheat. Thus in the case of a furnace heating material, such as steel to 1,300° C. by means of a producer gas preheated to 500°C, the percentage increase of heat returned to the furnace in air heated to 400 C and 600° C is 8·5 per cent and 12·5 per cent , assuming good combustion conditions

The gain in "theoretical temperature gradient" (*i.e* , the difference between the theoretical flame temperature and the working temperature of 1,300°C.) is, however, much more than this. The actual figures are 37·6 and 50 7 per cent respectively, for the same preheats.

The large refractory recuperator usually employed has, however, a high heat capacity, which diminishes its utility in the smaller and intermittent type of furnace. Further the fragility of the refractory material, its porosity, and the instablility of the joints, constitute further important disabilities in shops where heavy vibration and hammering occur. To obtain physical stability in such circumstances thick refractory walls are necessary. There is a limit to what can be done in this direction, because heat transmission is seriously reduced with the thickening of the walls

The logical alternative, combining lower thermal capacity with

enhanced utilisation of surface for heat transmission, is the development of the metallic recuperator. Until comparatively recent years cast iron and mild steel had been mostly used. They had, however, serious limitations as regards the temperatures to which they could be heated, and only limited degrees of preheat could be obtained, of the order of 300 to 400°C. at the best. Recent metallurgical advances have, however, produced heat resisting materials which can be obtained not only in cast forms of a high degree of intricacy, but in such machinable and malleable forms as to render possible the construction of a robust yet lighter recuperator. Further, the metallic recuperator permits high velocities to be carried, and accordingly an improved utilisation of available surface, since the transmission coefficients are thereby increased. Hitherto the parallel type of flow has been mostly used, since it tended to give the lowest maximum temperature in the walls The use of heat-resisting steels permits the use of the counter-flow type, which gives the highest degree of preheat. The most economical type for large recuperators is a combination of the cheaper types of material, cast iron, etc., for the sections working at low temperatures, up to 400° to 500°C., and heat resisting steel for the high temperature section.

A brief survey of the classical work applicable to the determination of the coefficients of heat transmission concerned in recuperator practice has been given by the authors elsewhere [10]

EXPERIENCE OF A LARGE INDUSTRIAL ORGANISATION WITH METALLIC RECUPERATORS

As an impartial indication of the state of progress in these developments, we cannot do better than quote from a private communication to one of us, embodying the experience of a large industrial organisation, which probably more than any other has made an exhaustive study of the subject:—

"CLASS OF FURNACE.—Our early experiments with metallic recuperators were made with a small coal-fired muffle furnace, about 18 12 in on the hearth, the recuperator being made of mild steel The recuperator was combined with a method of circulating the hot gases round the heating chamber of the furnace before entering the flue leading to the recuperator, so providing a jacket of hot gases tending to reduce conduction losses from the high temperature zones—the system being later patented by two of my officers here The use of this recuperator system was so successful that it was developed and nichrome and similar heat resisting metals employed for the recuperators and burner parts subjected to high temperatures The system was applied to practically all our new

"Fuel Economy Review," 1928

coal furnaces, and included crucible furnaces and large oven furnaces up to 10 × 8 ft. on the hearth.

"It was then used for producer-gas fired furnaces (coal gas retort settings, billet forging furnaces, and annealing ovens), but it was found that the sulphur content in the waste gases combined with the high temperature (up to 1,100°C.) caused rapid deterioration of the recuperator tubes, and the ferrous heat-resisting steel was very much better in this respect than the high nickel-chromium alloy. It still did not give sufficiently long life to render it an economical proposition where the waste gases contained much sulphur, and we are now using for this work similarly shaped tubes but without gills, made of firebrick or carborundum mixtures, with very satisfactory results, though naturally such a recuperator takes up considerably more room than one of metal of similar capacity.

"TYPE OF FUEL USED.—As stated above, metallic recuperators as shown in Figs. 2 to 5 are only used for relatively high furnace temperatures and with fuels relatively free from sulphur.

"Every endeavour is made to secure contra-flow operation of our recuperators, and this has been possible in every instance so far. The recuperators are relatively small, and are placed in the most convenient

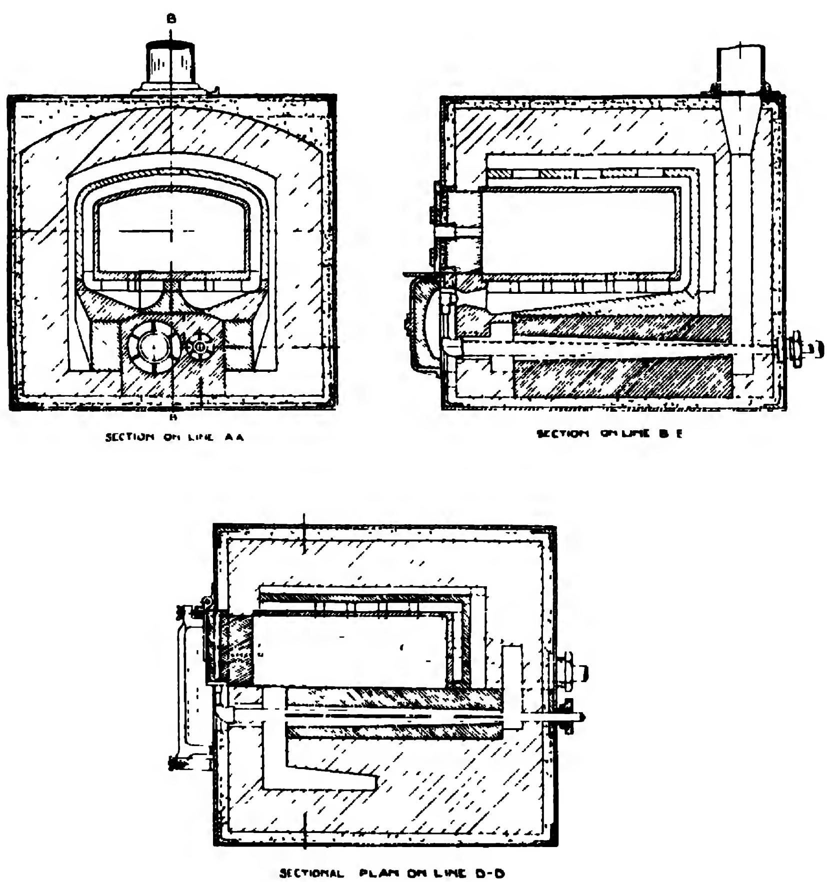
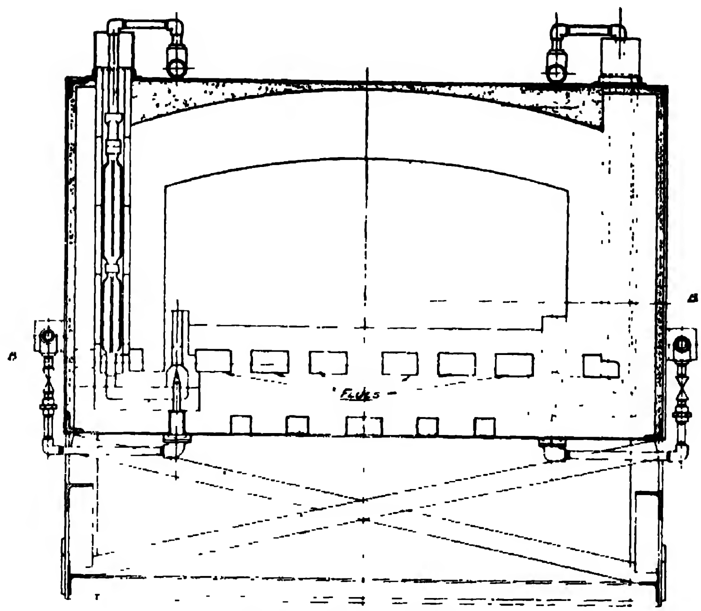
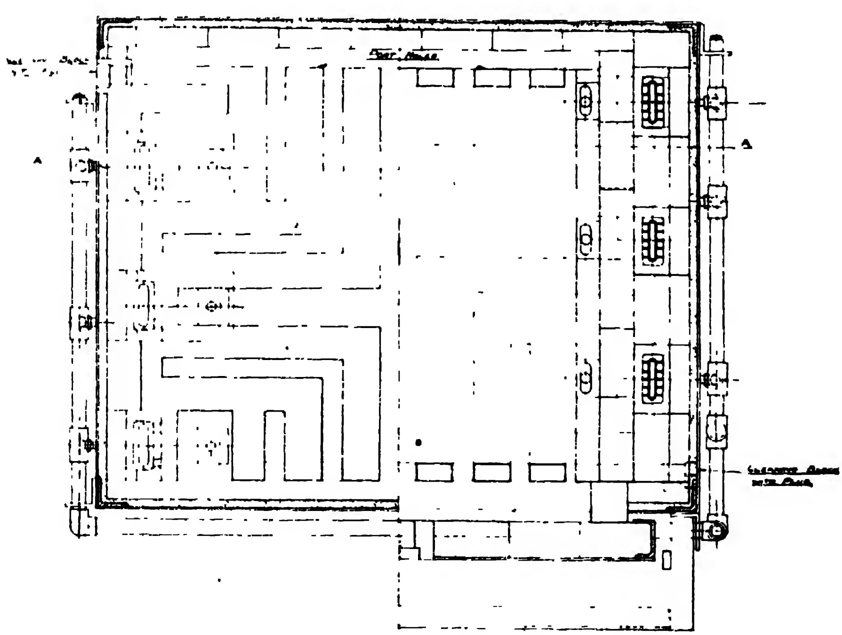


Fig. 2



CROSS SECTION ON LINE A A



SECTIONAL PLAN ON LINE B B

Fig. 3.

position for each design, being sometimes placed in batteries at one end of the furnace, or under the floor as shown in Fig 2, sometimes in separate units as part of the outer wall construction (Fig 3), and sometimes combined with a burner equipment as a separate unit (Fig 4).

"THERMAL EFFICIENCY (*a*) It has been our custom so far to apportion the recuperators so as to allow two 16 in tubes—detail obtainable from Figs 3 and 5 (inner surface of the two 2·55 sq ft, and outer surface 5·26 sq ft)—per therm per hour fuel consumption of the furnace, and in these conditions waste gases entering at 1,000° C are cooled to 300° C and the air heated to approximately 750° C in the process. Reckoning on the

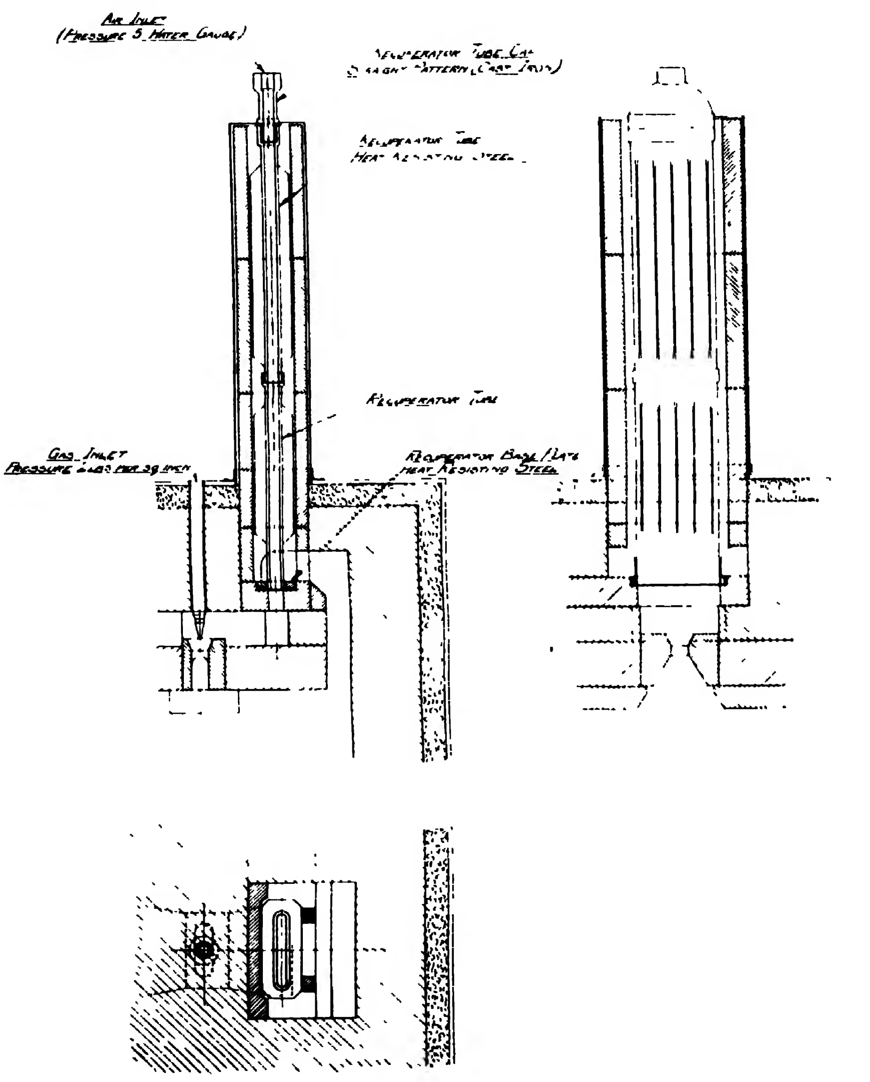
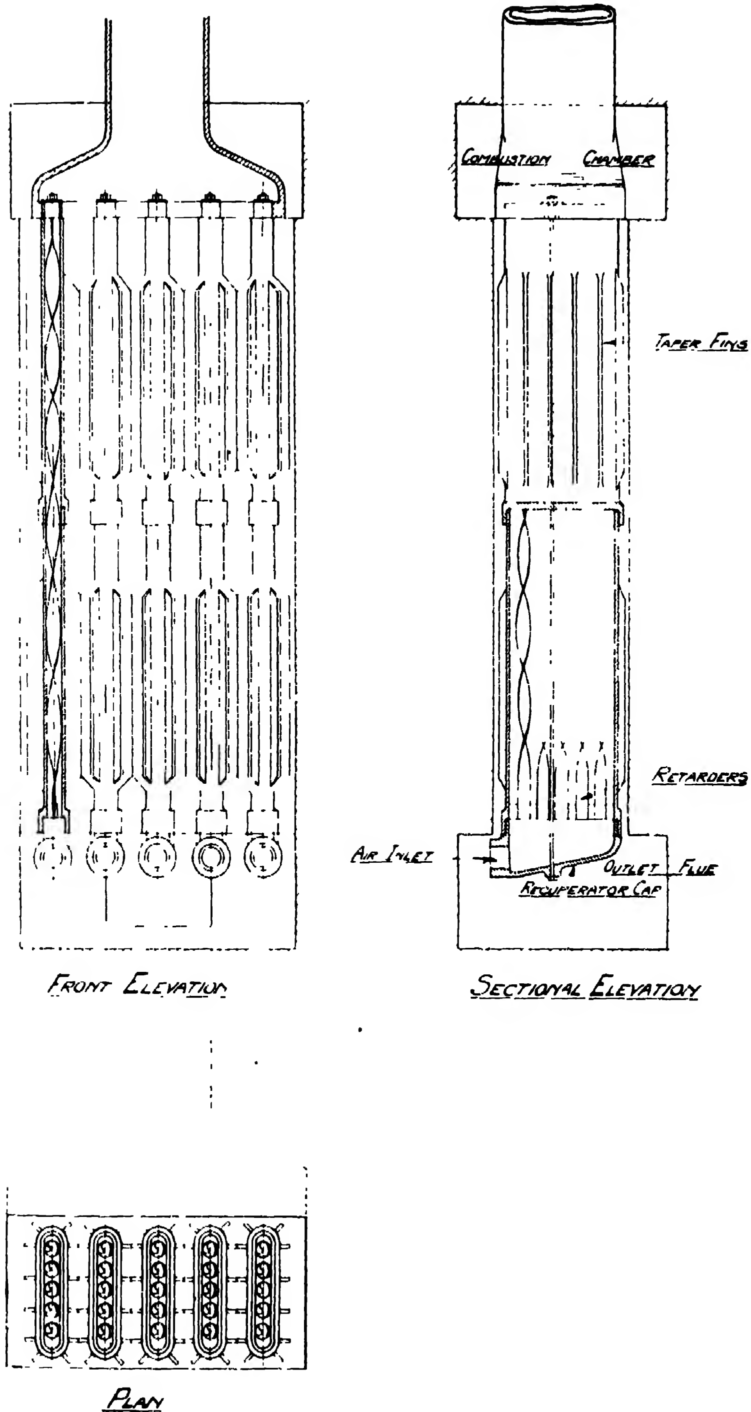


Fig 4



Combustion Chamber
Taper Fins
Retarders
Air Inlet
Outlet Flue
Recuperator Cap
Front Elevation
Sectional Elevation
Plan

Fig. 5.

area of the inner surface of the tube this gives a transmission of 10,440 B.Th.U. per sq. ft. per hour, with a mean temperature head of 225°C. (405°F.), giving a value of K of 25·8 B.Th.U. per hour per sq. ft. per 1°F. head. If the furnace is over or under loaded as compared with the above rate of fuel consumption—so increasing or decreasing the velocity of flow of gases, comparatively little difference in gas temperature is obtained, thus suggesting that the value of K is very nearly proportional to the gas velocity, but, of course, the effect of any such overloading is to increase seriously the frictional pressure drop in the gases, and some provision for overcoming this is necessary. The above will allow you to arrive at an approximation of the relation between the thermal efficiency and the preheat temperature, but as we have a fairly constant ratio here between transmitting surface and gas quality, our results only cover a comparatively narrow range of variations of gas velocity, say, of 25 per cent. above and below the mean.

"(*b*) As stated above, the temperature gradients in our practice are about 700°C. in a length of 32 in. on the waste gas side, and the temperature heads between gas and air between 200° and 300°C.; the rate of heat transmission has been given above. As regards thermal resistances, the somewhat complicated shapes of the passages used make calculation difficult, but all our results are consistent with the existence of a thin film—whose thickness varies almost exactly inversely with the gas velocity—of gas flowing in stream lines along the surface of the metal, and through which all heat has to be transmitted by conduction, and the thickness of this film can be calculated approximately from the result of Stanton's researches on the subject. Exact analysis of the problem has, however, not yet been undertaken.

"With regard to radiation, as you know, air and waste gases are practically diathermanous to radiation, but we have found that the insertion of twisted strips in the air space of the recuperators, as shown in Fig. 5, which increase the turbulence of flow and will act also as absorbents of radiation appreciably increases the heat transmission, though the relative effect of increased turbulence and radiation has not been studied.

"TEMPERATURE LIMITS.—We have not yet found a metal which will withstand greater working temperature than 1,100° for any period consistent with economic operation, and this allows of reaching a maximum of about 950°C. in the preheated air, the life of the metal reaching such temperatures may reach 12 months. Below 1,000°C. working temperatures the tubes have a life measured in years, deterioration being very slow."

The above represents an authoritative pronouncement of outstanding interest. The type of commercial furnace embodying the very interesting findings of these researches is known as the Roberts-Booth Furnace, the Patent Specification being No. 129,830.

Since the experiments cited were carried out, materials have been developed which give an enhanced resistance to sulphurous gases compared with the duty obtainable from the material then available. Considerable quantities of such material are used for mechanical

rabbles for sulphide ore roasting furnaces, as well as for a variety of uses in oil-fired furnaces operating up to 1,100°C.

METALLIC RECUPERATOR APPLIED TO COAL-FIRED FURNACES

While the gas or oil-fired furnace is highly desirable for many reasons in all classes of industrial practice, it is unlikely that furnace firing with solid fuel will be superseded for some time to come.

Attempts to preheat secondary air in coal-fired furnaces, even of the semi-producer type, are not fully effective. At the best only 65 per cent. of the total air required is available for preheat, unless undue proportions of excess air are used, and experience has shown that in many cases the requirement of secondary air is as low as 10 per cent. of the total volume used. On the other hand, if a means can be devised for burning coal directly with highly preheated primary air, a large measure of thermal economy is possible. The natural limitation is imposed by the formation of clinker due to fusion of the ash. On large grates direct combustion without some admixture of steam, either supplied direct or vapourised or atomised below the grate, is not readily attained below moderate rates of combustion. Under such conditions moderate preheats have been used. This practice involves the utilisation of fan draught, which has advantages compared with the steam injector. The latter uses steam to the extent of 1 lb. per lb. of coal burnt, and upwards, whereas the fan power required to supply air to burn coal under a draught of 6 in. water gauge is only about 0·4 kW. per cwt. of fuel per hour.

At the Hecla Works of Messrs. Hadfields Ltd., of Sheffield, the heat-resisting steel recuperator has been applied successfully to give moderate preheat to primary air in coal-fired forge furnaces without the use of any steam or water. In this design the recuperator consists of a series of straight tubes placed in a chamber below the hearth, through which the hot waste gases are led in such a manner as to form a combined counter-flow and parallel-flow arrangement. The inlet gases to the recuperator are at a temperature of 1,100°C. to 1,200°C. The hot air passing through the tubes under forced draught at very high velocities is fed directly below the grate.

When heating 3½ in. billets and blooms at the rate of 19 lb. per sq. ft. of hearth area per hour on a hearth area of 24 sq. ft. to a temperature of 1,100°C. to 1,150°C. the fuel consumption is 3·25 cwt. of coal (12,300 B Th.U. per lb.) per ton of material charged. The coal figure covers the total quantity of coal used for heating up and

operating the furnaces, which are only used on the day-shift. The preheat obtained on the air is approximately 300°C., the return of heat to the furnace, being in the case specified, 12 per cent. of the total heat input of the fuel Under the conditions obtaining, namely, a small grate and a rate of combustion of 20 to 40 lb. per sq ft. per hour, no clinkering trouble has been experienced using local hard coal with an ash refractoriness of 1,350 to 1,500°C. These recuperator tubes of heat-resisting steel have already been in use 18 months, and do not show the least sign of deterioration.

In order to gain full advantage of the intensity of utilisation of surface possible with metallic recuperators it is necessary to make provision for periodic cleaning This lack of accessibility for cleaning is one of the disabilities of a bent pipe type, for even though the inaccessible region may only be carrying air, the soot and dust inevitable in the atmosphere of a workshop tends to accumulate on the surface of the tubes, and interfere with their efficiency

In the case of the furnaces cited above, a special provision is made for dealing with the secondary air, which, combined with the use of preheated air has been successful in enabling the furnaces to be operated without the production of undesirable quantities of smoke

REGENERATORS

Passing on to another effective means of recovering waste heat, that of the reversing regenerator, an interesting course of investigation has been undertaken in the Research Department of the authors' firm with the object of determining the actual heat transmission coefficients obtained in regenerator settings of various types. The measurement of the temperature and flow of gases through a regenerator is not readily achieved. An alternative method has been adopted, which is being carried out in conjunction with the former method Through sight holes provided at different levels the distribution of temperature throughout the chequer work is being explored by means of an optical pyrometer sighted on the brickwork. The course of the cyclical change is followed by taking series of readings, and the temperature gradients at successive intervals of time after reversal are derived from these observations. Close analysis of the curves reveals the gas flow to be vertical.

In order to determine the actual saturation of the brickwork following such a course of changes a similar chequerwork arranged

in 6×3 in. openings, with the usual deposit of dust on them, was built in a gas furnace, with a thermo-couple inserted inside one of the bricks at a median point at which it was estimated a mean measure of the saturation would be obtained. This experimental setting was subjected to the same cyclical variations observed in practice, and the course of saturation determined. It was found that the saturation percentage expressed as a ratio of the true change of temperature throughout the brick (namely, a 3 in. square, $9\times4\frac{1}{2}\times3$ in., Silica brick), to the observed change of temperature on the face varied with the rate of the latter. Curves of the relation were drawn, which showed that the saturation varied from 65 per cent., with an average rate of change of 5°C. per minute, to 50 per cent., with a change of 2·5°C. per minute—in the case of bricks which had been in service some time.

Applying the data, obtained on bricks from different levels, to the change of temperature at the various levels and their known specific heats and densities, a relation between the heat exchange in a given cycle and the depth in the chequer work was derived.

The results for a cooling cycle, heating ingoing air, on an air chequer in a 30-ton acid open hearth furnace were as follows: The greatest temperature change occurs in the upper courses of the chequer brickwork. It falls off in descent of the chequer work, according to a law, which has been sometimes observed to be linear, though cases have been observed of it differing and tending to become hyperbolic. As an instance in a chequer 15 ft. long × 9 ft. wide the cyclical change dropped from 120°C. to 65°C. in 5 ft. for a mean temperature of 800°C. The heat exchanges corresponding were of the order of 700 B.Th.U. per sq. ft. of exposed brickwork per hour for the top, and 300 B.Th.U. per sq. ft. per hour for the lower point. The mass velocity of the incoming air was 0·025 lb. per sec. per sq. ft.

An important conclusion to be derived from these observations is that the hotter sections of the chequer work are the more effective in preheating capacity, and that, therefore, the chequer work should be built as close to the furnace ports as the separation of slaggy material from the gases will permit. The older open hearth furnaces with downtakes opening into chequer work had a reputation for hot working; and it is apparent that by making large slag pockets colder working must result. The same conclusions are more readily applicable to heating furnaces using regenerators in which there are no slag troubles.

FLOW OF HEAT THROUGH FURNACE WALLS

The measure of the intermittency of the furnace operation, or more particularly the periodic fluctuations which the furnace must undergo is a dominant factor in determining not only the loss of heat stored in, or lost through the furnace wall, but also the proportion of that heat which may be recovered into the charge and so utilised : these considerations determine the dimensions of the wall. The furnace wall performs an important function in the maintenance of a hot radiating surface, and, in the case of "in and out" furnaces, the storage capacity of the wall may govern the permissible rate of operation. In such a case the theoretical ideal is obtained by having an inner wall of high refractoriness, sufficient in volume only to carry the desired fluctuation of storage of heat, this latter property demanding a high heat conductivity, and an outer wall of heat insulating material. This ideal combination has not yet been obtained, because of the failure of the materials available to give the desired properties. Mechanical difficulties of constructing thin refractory walls, and the point of failure of the most effective insulating materials at temperatures above 800°C. to 1,000°C., constitute the chief disabilities. Further, the rates of heat flow through refractory walls actually obtained under periodic change in industrial practice are not known with any certainty, though they may be calculated by the application of the Fourier series under certain defined conditions.

The experiments here outlined indicate a direction in which research is being prosecuted in the Research Department of the authors' firm This is not the occasion to attempt more than to indicate the problem and the means by which it is being attacked. The periodic fluctuation of temperature gradient is being experimentally explored by means of thermo-couples placed in the walls of various types of furnaces in service, the temperature changes being obtained from recording pyrometers. The total heat capacity is derived from the observed temperature gradients and the volumetric heat of the material used, that is to say, the heat capacity per unit volume. The heat absorption curves marked "A" in Fig. 6 were obtained in this manner, and refer to the total capacity of the whole wall.

SURFACE LOSSES

In the absence at present of a more accurate means of determining the surface heat loss, the method of calculating the combined radiation and convection losses from the surface temperature has

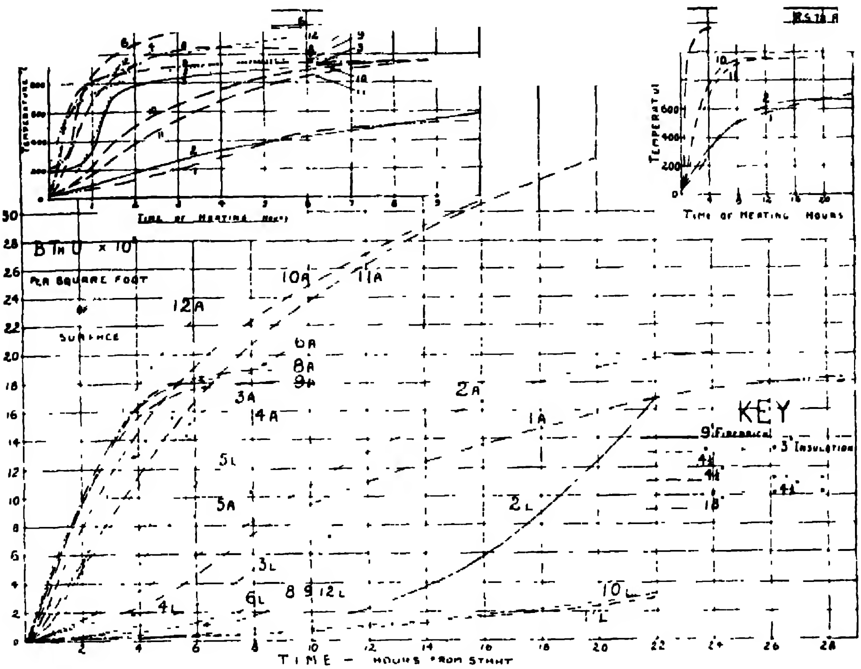


Fig. 6.

been employed. The curves of surface heat loss are marked "L" in Fig. 6. The surface temperatures have been deduced from the temperature gradients, and checked independently by two types of surface contact couple. One of these embodies the use of two thermo-couples, the one forming a flat surface to give contact, the other being placed adjacent to it. The heat loss along the first couple is controlled by a small electric heating element. The second couple is used to balance the gradients, and to obtain an almost instantaneous reading of the surface temperature. Experiments have also been made with lagged copper blocks, carrying guard rings, placed against the furnace wall, the heat absorption being deduced from the observed rate of rise of temperature of the copper. This offers a promising direction of enquiry over a limited range of temperature and conditions. It does not apply where strong convection currents or draughts are encountered, the measurement

TABLE XII.

	Firebrick. Best quality Derby clay.	Insulation. A.	B.
Density gr./c.c. .			
Apparent	1·98	0·56	·65
True	2·6	2·40	2·35
Porosity percentage	24	76·70	72·30
Heat conductivity			
C.G.S./units	0·0020	0·00036	0·00042

of the effect of which constitutes a complex problem. The line of attack being adopted is to work with models placed in a draught tunnel equipped with a fan. The work of Griffiths and Davis[11] at the National Physical Laboratory has indicated the validity of this method.

The results of the experiments are summarised in Fig. 6, the key to which is given in Table XIII. In Table XII. are given the physical properties of the materials used.

TABLE XIII.

Group	Expt No	Wall Inches thickness: Firebrick	Wall Inches thickness: Insulation	Maximum surface temp °C	Time to reach max temp Hours	Estimated time to reach steady state Hours	Time at which external surface loss totals 2,000 B Th U. per sq ft Hours	Remarks.
I.	1	18		750 1,040	40 115	40 115	36	Very slow heating, cyclical heating after 20 hours. Open hearth furnace chequer wall
	2	9	—	750	9	25	11·5	
	3	9	—	780 960	2 8	10	5·4	Wide differences due to heating rates
	4	4½	—	1,150	4	see dotted curve.	3·7	
	5	4½	—	950	5	7	2·4	Short test and steady state not reached.
II	10	9	3 A	950	7·5	not soaked after	17·1	Slow rates of heating
	11	9	3·A	950	9	20 hours	18·3	
	6	4½	3 A	1,150	3	8·5	7·4	
	8	4½	3 A	1,000	3·5	7	7·0	Rapid rates of heating.
	9	4½	3 A	950	3	7	7·0	
	12	4½	4½ B	800 1,140	1 6		7·0	Rapid heating, no indication of soaking

In Group I. for the same increment of temperature of the heated surface the total quantity of heat stored at any instant in the wall depends almost entirely on the rate of heating. Also the heat loss from the external surface is similarly strongly influenced.

In the case of the insulated walls in Group II. the influence of the rate of heating is less definite, and the manner in which the heat storage is raised is clearly shown. Study of the surface loss curves indicates the time at which the effect of the insulation begins to show an advantage in any one thickness of wall. Thus for the 9-in. firebrick wall, No. 2 as compared with Nos. 10 and 11, after 10 hours the insulation begins to exert its effect. Similarly for the 4½-in. wall a wide difference is shown after only 2½ hours.

When the inside face of the 4½-in. insulated wall is raised to 1,150°C., the temperatures obtained for the steady state, at the interface of the firebrick and the insulating brick is 835°C. For a 3-in. insulated

[11] Papers on "Convection of Heat" in N P.L. Collected Researches, Vol XIX. 1926 p. 183 *et seq.*

wall it is above 950°C. At these temperatures many of the best insulating materials of the diatomaceous earth type begin to shrink and lose their value. There is, therefore, a field for insulating material which will withstand indefinitely these conditions. Such material is already obtainable, as for instance in brick B, but as will be seen from the heat conductivity value, less insulation is obtained.

The actual heat storage in the insulating brick is almost negligible. Thus in Experiment 10 after 16 hours it is only 4·5 per cent of the heat stored in the firebrick In Experiment 11 after 20 hours it is 3·5 per cent.

The point at which the surface heat loss exceeds the brickwork storage is indicated in certain cases. For a 4½ in. bare wall it occurs at 5 to 8 hours according to the rate of heating, but when such a wall is insulated the surface heat loss does not appreciably exceed 10 per cent. of the brickwork storage in the same period.

The experiments mentioned form the preliminaries to a projected investigation, designed to cover not only refractory materials, but the material of the charge, heated in the furnace, with regard to which data available is all too meagre. Correlation with the accepted methods of computation is being carried out.

CONCLUSIONS

The main conclusions arrived at and presented in this general survey of Industrial Heating by Solid, Liquid and Gaseous Fuels may be summarised as follows: -

(i) The value of the adaptability factor which is a function of the technical developments in furnaces, is higher in the case of gaseous and liquid fuels, and discounts, in a degree varying with the specific conditions of an operation, the lower therm cost of the solid fuel.

(ii) There is considerable scope for the direct application of solid fuel by further development of the mechanical stoker and other means of burning solid fuel (*e.g.* pulverising), combined with preheating of primary air.

(iii) The mechanical furnace involving the use of heat resisting materials is a means of obtaining continuous working associated with the most economical load, and efficient operation.

(iv) Metallic recuperators, of heat-resisting alloys, operating at high temperatures have proved to be practicable and valuable aids to fuel economy. They have also been successfully applied to preheating primary air in coal-fired furnaces. This subject has been fully dealt with in the Paper on "Heat Resisting Steels."

by Sir Robert Hadfield and Mr. R. J. Sarjant, which appeared in the July issue (Vol. VII., 1928) of "The Fuel Economy Review" published by the Federation of British Industries.

(v) In an investigation of air regenerators the coefficient of heat exchange per unit of surface area was found to increase in value as the path of the heated gas was ascended. This change of preheating effectiveness in the upper sections of the regenerator suggests that the chequer work should be built as near to the furnace ports as is consistent with the separation of slaggy material.

(vi) In a preliminary study of the flow of heat through furnace walls, the influence of the rate of heating has been shown to exert a marked influence on the relative storage of heat in unlagged firebrick walls, as compared with the external surface losses. The insulating material is shown to become effective in reducing losses within a few hours on 4½ in. firebrick walls, and after 8 to 12 hours with 9 in. walls. In the case of very slow heating, however, the time is longer at which the effectiveness is apparent.

Our best thanks are due to Mr. W. J. Dawson, Metallurgical Director of Messrs Hadfields Ltd., for his suggestions and interest in connection with the investigations reported in the paper, also to Messrs. E. W. Gregory and D. Knowles, both Associates in Metallurgy of Sheffield University, members of the Hadfield Research Staff, for their assistance in the experimental side of the work.

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RÉSUMÉ

Les valeurs relatives des combustibles pour chauffage industriel sont considérées aux points de vue de leur valeur économique actuelle et de l'influence du facteur adaptation. Le combustible solide a l'avantage que son prix de revient par thermie est relativement faible, mais les combustibles gazeux et l'huile sont plus faciles à appliquer.

On discute en détail les possibilités d'application des divers combustibles par rapport aux derniers développements techniques.

La proportion de gaz municipal utilisée en Grande Bretagne pour le chauffage industriel est probablement d'environ 10 pour cent de la production totale. La consommation industrielle augmente à raison d'un pour cent par an de la consommation totale. On passe en revue la consommation de gaz et de houille dans les différentes opérations.

On établit un rapport définitif entre la surface de chauffe et le rendement thermique dans certains types de fours. On insiste sur la nécessité du contrôle pyrométrique de la vitesse de chauffage pour donner des résultats économiques.

Discussion assez détaillée de l'économie de chaleur par récupération; on signale les progrès dans l'application du récupérateur métallique opérant à hautes températures avec notice spéciale concernant l'expérience d'un grand établissement industriel

On signale l'emploi d'aciers spéciaux résistant aux hautes températures et l'on fournit la preuve de leur application heureuse dans le chauffage préalable de l'air primaire dans les fours chauffés au charbon.

On esquisse l'examen de recherches concernant les coefficients d'échange calorifique pour les régénérateurs, en signalant l'intérêt qu'il y a à placer les régénérateurs aussi près des portes des fours que possible, dans la mesure où cela est compatible avec l'élimination des inconvénients de la scorification.

On discute les expériences préliminaires d'une étude sur l'écoulement de la chaleur par les parois des fours, surtout au point de vue du rapport entre l'accumulation de chaleur dans la maçonnerie et les pertes à la surface extérieure pour le chauffage périodique et intermittent.

INDUSTRIAL ELECTRIC HEATING

BRITISH ELECTRICAL DEVELOPMENT ASSOCIATION

S. E. MONKHOUSE

*Paper No. K*10

CONTENTS

[The illustrations to this Paper have been added since its presentation as a Fuel Conference proof at the time of the Conference]

INTRODUCTORY

With the advent of a clearer perception on the part of the industrial community of the value of having an abundant supply of electric power available in this country, and of the electrical era which we have undoubtedly entered as a result, many papers have been written upon the numerous uses to which the electric service can be applied, and it is not inappropriate in consequence that the present occasion should be made use of to consider what advantages, if any, are to be obtained by the user, as a result of the adoption of electricity for supplying industrial heating requirements.

A vast sum of money has already been expended in this country on the provision of the plant and networks necessary for affording supplies of electric power, and in view of recent legislation, and the expenditure that is to be incurred in the provision of capital power stations and main transmission lines, it is in the interests of all, the supply authorities and the consumers alike, that every consideration should be given to, and all means adopted for, extending the use made of this service so as to lower the cost of production and reduce the price charged to the consumer.

Many processes making use of night heating can effect material savings by using electricity as the heating agent, for by this means automatic control can be employed with a great saving on account of labour as a result.

This paper lays no claim that electricity is the "cure for all ills," or the best form of service to use for all purposes. It merely asserts that for a great many heating purposes it is the ideal agent to employ.

This paper is not written without a full appreciation that gas, oil, and solid fuels each have their own uses and hold their own fields, but rather with the desire to emphasise that, whilst electricity likewise has its field and its uses, this field has not yet been fully developed, for various reasons such as infancy and lack of propaganda.

There are a large number of electric heating installations in successful operation in different parts of England, and it is unfortunate that little or no publicity has been given to them, particularly when the publicity given to similar installations in other countries is such as to give the impression that electric power can only be used for these purposes economically in countries where water power is available.

It has frequently been stated that, in view of the conversion losses, electricity for heating purposes is extravagant in the consumption of coal for a given return in energy. It is not, however,

correct to compare directly the consumption of electricity with that of fuel. When electricity is delivered for industrial heating purposes a large percentage is usefully employed, in fact it would be almost true to say that for this purpose it is 100 per cent. efficient, whereas when the efficiency of fuel burning apparatus is considered, it is discovered what a very low percentage of heat energy reaches the desired object.

It may be well to attempt to form some idea of the amount of energy that is being consumed annually in this country for the purpose of providing the heat required to operate some of the various processes in daily use in our factories. No statistics are available which will permit any definite statement being made on this subject, nor is it possible to frame any accurate estimate, but the result of an actual investigation of certain individual works of various classes is enlightening.

The following table shows a direct comparison expressed in B.Th.U. between the quantity of fuel and of electricity used for heating and power purposes respectively in a few cases which have been examined. Each case taken was a typical example of the particular industry selected, and in each case all the power plant was driven electrically.

	Fuel in million B.Th.U.	Electricity in million B.Th.U.	Percentage electricity to fuel
(1) Shipyard and Engineering Works	118,900	3,480	2 9
(2) Engineering Works and Brass Foundry	9,080	581	6 5
(3) Paint Works	4,844	122·8	2 54
(4) Soap Works	104,600	493	·47
(5) Pottery	2,203,900	905	·45
(6) Bakery	15,760	296	1·88

The figures comprising this table have been taken from statistics of individual works and should, of course, only be used as a general indication of the relative energy consumptions for heating and power in the industries tabulated.

But, even if allowance is made for a wide variation in these figures, it remains apparent that if electricity were employed as a heating agent for those purposes only for which it is ideal, there would be a very large proportional increase in the consumption of electrical energy. Therefore, it is only proposed in the present paper to deal with those applications which are suitable for electric heating in this country.

This can best be done by referring to processes which are working in the British Isles and which, as a result of actual experience under commercial working conditions, have been proved to be more satisfactory when electrically operated than they were when heat was obtained by other means.

No mention is made in this paper of the relative prices of fuel and electricity, the comparisons having been made on the basis of the price ruling for each commodity in the district in which the apparatus is in use.

The broad scope of this subject prevents detailed reference to each of the multitude of industrial heating processes, but it is felt that the descriptions which follow will show the line of present development, and be to some extent an indication of the future that is to be expected for heating by electricity in this country.

Broadly speaking, heating applications can be divided into sections by temperature, *i.e.*, those operating below 500°C., those which require a medium temperature between 500°C. and 1,000°C. and those working above 1,000°C., and it is along these lines that the various applications are dealt with in this paper.

I.—PROCESSES MAKING USE OF TEMPERATURES UP TO 500°C.

Ovens for Paint Drying

Colour media used for paint making are prepared by a process involving the reaction of various chemicals, the medium being collected in the form of a precipitate containing from 50 to 90 per cent. of water by weight. The colour medium has to be dried before it can be used for paint manufacture, and this is usually carried out by spreading it on wooden trays in long stoves, the trays being arranged either on trucks or on shelves.

The drying stoves are generally heated by a current of hot air which is circulated in the stove by means of a fan, and it is important that the temperature of this air should not exceed 75°C., otherwise certain colours may be spoiled. Where trucks are not employed the process of drying is very inefficient as the doors are open for long periods for the purpose of loading and unloading.

As steam is used in paint works in connection with their manufacturing processes, the usual method of heating the drying stoves is to pass air over a nest of steam coils placed in the stove. This arrangement, however, has the serious disadvantage that it is costly to run the stoves all night, as it entails running a boiler

involving cost of labour merely for the purpose of supplying the small quantity of steam required by the stove.

In order to meet this difficulty drying stoves have been converted to electric heating, by placing electric heaters alongside the steam heaters so that either can be used as desired; and in cases where this has been done it has become the usual method of operation to use steam heating during the day and electric heating at night and week-ends when the boiler plant is shut down. Under such conditions, it is economically possible to heat the stove continuously, particularly as the electrical load is entirely off peak, and therefore obtained at a low rate.

Tempering Hardened Steel

The object of tempering hardened steel is to reduce its rigidity, so as to permit it to bend slightly to a blow that would otherwise fracture it if left in the original hardened condition; but as tempering reduces cutting power and endurance it follows that it should not be carried further than is absolutely necessary to secure the required flexibility.

The process of tempering, therefore, should be carried out with considerable precision, and at certain definite temperatures according to the nature of the work; these temperatures in general range between 200°C. and 300°C., the former being required for cutlery and the latter for springs.

One of the chief merits of electric tempering lies in the ease by which adjustable automatic temperature control can be brought into employment.

Tempering equipment divides itself into two classes:

(*a*) Baths.
(*b*) Ovens.

Baths consist of a container holding oil, lead or salts which are heated to the required temperature and into which the steel is immersed for treatment; once the heating medium has been brought up to temperature, the bath is rapid in action and is well suited for continuous work.

Ovens, on the other hand, require very little energy to obtain the required temperature, but are slow in heating the work unless fans are employed.

As an example of the relative performance of these two types it may be said that taking the time to heat a charge in a plain oven as unity, the addition of a fan will reduce the time to one-third, and in the case of an oil bath, the same work can be carried out in

one-ninth of the time. The tempering of steel in electric furnaces is now common practice in England, and the following data have been obtained under practical conditions :—

(*a*) To heat steel up to 250°C. above room temperature requires 16·5 Wh. per lb.

(*b*) Allowing for heat losses, the consumptions are as follows :—

Bath	24 Wh. per lb.
Oven with fan ...	37 Wh. per lb.
Oven without fan ...	110 Wh. per lb.

Under the worst case, *i.e.*, 110 Wh. per lb. or say 9 lb. for 1 kWh., electric heating has proved a commercial success, principally owing to the saving of labour resulting from the employment of automatic control.

STEAM RAISING

Steam raising by electricity, of which there are many noteworthy installations in operation on the Continent and in America, is a very recent introduction in this country, but there are already indications that it will be adopted here for special purposes.

This is particularly the case in factories where steam is required either intermittently, as in dairies where a small quantity of steam is used twice a day for sterilising purposes, or where steam is wanted in small quantites at distantly situated parts of the works.

For such cases a small steam generator is used in conjunction with a steam accumulator ; by this means steam is produced during off-peak hours with current at its cheapest rate, the steam being drawn from the storage during the day time.

As the only loss in an electric boiler is by radiation, the efficiency is very high, being in the order of 90 per cent. ; and in practice, at a pressure of 60 lb. per square inch, the power consumption is approximately 0·363 kWh. per lb. of steam raised.

At the present time and under existing conditions, electric boilers necessarily have a very limited application in this country, and in those cases where they have been adopted they are employed for one or more of the following reasons:—

(*a*) Small amount of floor space required.

(*b*) No flues or fuel storage required.

(*c*) Steam is raised very quickly.

(*d*) Low maintenance, as no part of the boiler is at a higher temperature than the steam generated.

(*e*) No banking losses.

(*f*) Long lengths of steam pipes eliminated.

BREAD AND CONFECTIONERY BAKING OVENS

In the preparation of baked foodstuffs two factors are of prime importance:—

Cleanliness, and

Close control of temperature and of heat distribution in the oven.

Electricity, in both respects, is superior as a heating agent to any form of fuel, and since the cost of the actual baking process is but a relatively small proportion of the total cost of manufacture of bread and confectionery—labour and material being the principal items—the extra cost of electric heat is outweighed by the improved results obtained, and the improvement in working conditions.

For the reason that baking is not a localised industry, there is a potential market for electric ovens in practically every town and village in the country; therefore, electrical manufacturers have been encouraged to enter the field, with the result that a considerable number of extremely efficient ovens of various types have already been developed.

Electrical bakery installations of the following types are in operation in this country:—

(A) PEEL OVEN

This is the simplest and commonest type of electric oven in use, and takes the form of a rectangular box of clear internal height about 9 in. to 18 in., and of varying "sole" area, common sizes being 3 ft. ×3 ft., 4 ft. ×4 ft., 7 ft. ×5 ft., 8 ft. ×4 ft., and 8 ft. ×6 ft.

The heating elements are usually of the tubular type and are fitted both in the top of the oven and below the sole or hearth. The top and bottom elements respectively are usually under separate control, the baker thus being enabled to regulate within fine limits the intensity of "top" or "bottom" heat applied to the goods.

Ovens of this type are equally suitable for the baking of either bread or confectionery.

(B) DRAWPLATE OVENS

Ovens of this type are suitable for both bread and confectionery, and consist essentially of a low rectangular-shaped oven, fitted with top and bottom heating elements, but in place of the fixed "sole" of the Peel oven, is a "drawplate" which can be withdrawn from the front of the oven for loading and unloading purposes.

(C) REEL AND TRAVELLING TYPE OVENS

These types have been developed with a view to ensuring uniform

baking by slowly and continuously conveying all goods round the oven during the process of baking.

In the "Reel" oven the goods are carried on trays suspended round the peripheries of a pair of wheels, and in the "Travelling" oven the goods are loaded at one end of the oven and discharged at the other.

Electrically heated ovens of this latter type up to a capacity of about 1,000 lb. of bread per hour, and having a loading of 80 to 90 kW., are now in use in this country.

A number of tests have been carried out under normal working conditions, of which the following are two examples:—

1. The oven, having a capacity of 112 2-lb. loaves, has a loading capacity of 25 kW. It is automatically controlled so that the supply is cut off when a predetermined temperature is reached, and switched on when the temperature falls below that figure, so that an even temperature is maintained to the advantage of the bake, and the saving of current.

   The test lasted 20 hours, including approximately one hour for heating up and one hour for meals.

   Twenty-four batches of bread, using 14 sacks of flour, were baked by one man and a boy and the current metered was 452 kWh., *i.e.*, 32 kWh. per sack.

   The average time taken to bake each batch, including loading and unloading, was 45 minutes.

   The yield was 96 4-lb. loaves per sack, which, compared with an average of 92 per sack when baked in a coal fired oven, showing a saving of three shillings per sack on the basis of a retail price of ninepence per quartern loaf.

2. A conveyor type baking oven, having a capacity of about 4 cwt. of slab cake, was tested over a period of twenty-four working days, when the oven was run for 255½ hours. A variety of confectionery goods requiring temperatures ranging from 160°C. to 280°C. was baked, of the retail value of £1,484 12s. 0d., with a total consumption during the month (including heating up) of 4,652 kWh. This is an average loading of 18·2 kW. or 3·12 kWh. per £1 worth of goods baked.

HEATING OF LARGE BUILDINGS

There has been a steady increase in the demand for electrical energy for domestic heating purposes during recent years, and the low-temperature electric radiator is a popular electrical appliance.

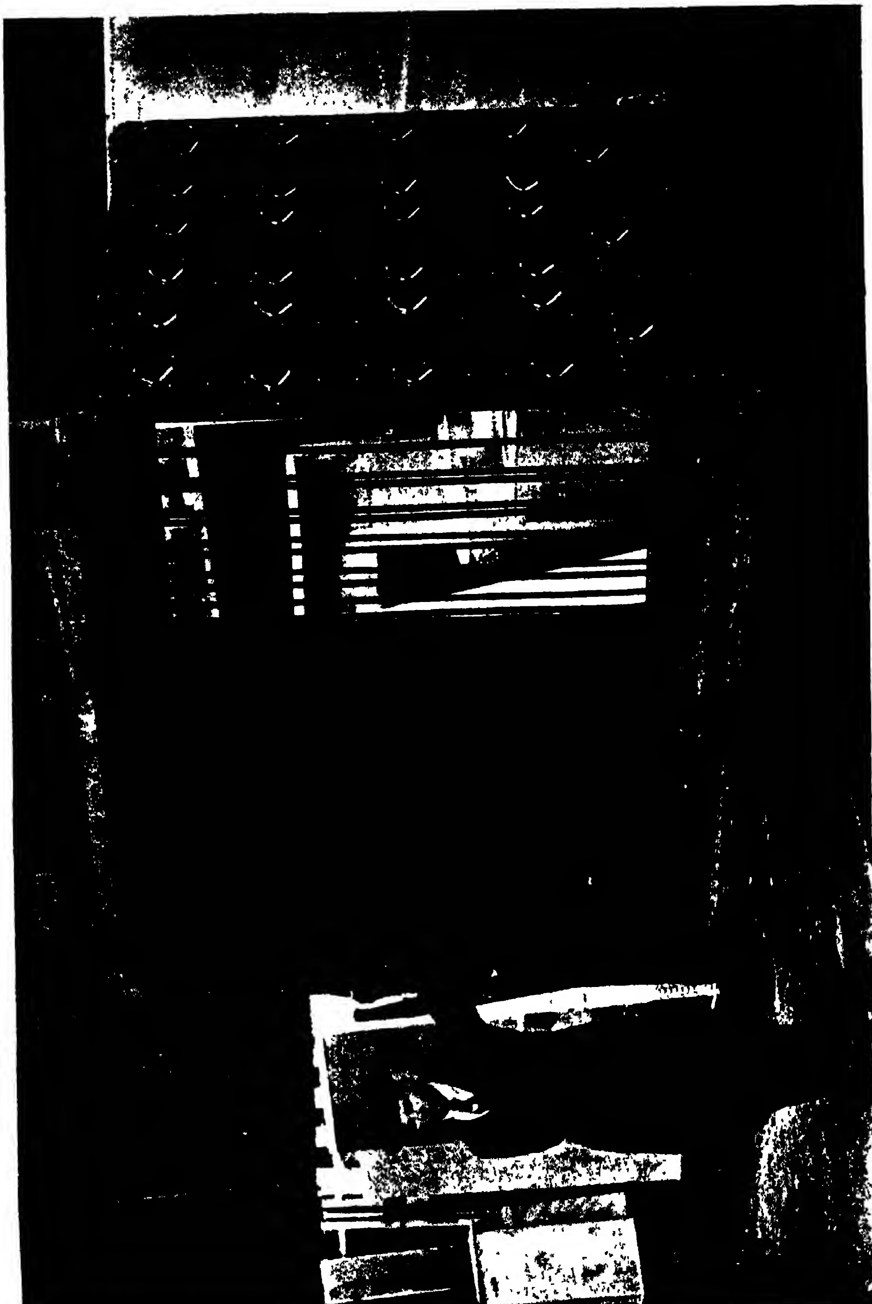

Fig. 1 —A 300-kW Air Heater used for warming the air in a Plenum System

It is noteworthy that the recent progressive stage of scientific development toward thorough effectiveness of large heating installations has coincided with an increased proportion of radiation, and a correspondingly reduced proportion of convection, as a means of transmitting warmth, and as considerable economies can be effected by installing radiant, as opposed to convection, heating appliances, electric heating upon a large scale has now become practicable.

Already there are at work in this country large electrical heating installations of each of the following types:—

(1) *Plenum Systems*, in which air, suitably conditioned as regards temperature, is propelled through ducts, and discharged at a point or points located within the enclosure to be warmed.

By means of this arrangement the temperature of the air may be varied to suit climatic conditions, and, as in this country legislation provides in several cases for the maintenance of a specified standard of air purity, it is often convenient to embody in the one installation suitable devices by means of which air may be conditioned, not only as regards temperature, but also with respect to purity and humidity.

(2) *Unit System*, in which each individual heat emitter, whether radiator or convector, is provided with its own heat generator and is disposed so as most effectively to warm a restricted area.

Electrically heated units having a comparatively large effective area, but designed to operate at low surface temperatures such as are usual with low-pressure hot water installations, are being used in large numbers, and from these about 50 per cent. of the heat available is transmitted by low-temperature radiation, the remainder being by convection currents.

(3) *Central Heating Systems*, in which steam or hot water, generated by central boiler plant, is circulated through pipes to and from comparatively low temperature heat-emitting devices located at fixed points in the building.

During recent years this system of central heating, using either solid or oil fuel boiler plant, has been installed almost universally in public buildings and large business premises.

Central heating installations are now working in this country which are entirely dependent upon electricity for the heating of the circulating water, a system of thermal storage being provided, by which means advantage may be taken of an off-peak tariff.

Where a high-tension supply is available, boilers of the three-phase immersed electrode type are being made use of, as such boilers

take up comparatively little room, notwithstanding that their electrical rating may be considerable. The usual arrangement is for steam to be generated at medium pressure, and for the circulating water to be heated by a process of heat transfer from steam to water with the aid of suitably designed calorifier equipment.

With a combination of high-tension electric boilers and thermal storage apparatus, a building of large dimensions can be heated effectively and economically, and there are now a few examples of such installations working in this country. In one of these the calculated energy required for heating purposes corresponds to 1,000 kW. during about eight hours each night in winter time, and, as ultimately the building is to be enlarged, the plant installed includes two 1,000 kW. 6,000 volt electric boilers of the type described.

Enamel Stoving

The black enamel used for coating metal such as cycle and motor parts, etc., consists essentially of an asphaltic compound, linseed oil and a solvent such as naphtha; and when applied to an article and then heated or "stoved," the solvent is driven off and the oil oxidised, leaving a hard elastic finish.

Successful stoving depends principally upon cleanliness, not only of the enamel itself but also of the atmosphere in the oven, and it is largely for this reason that electricity is now extensively used as a heating medium for this purpose, since it heats the air without in any way vitiating it.

Fine soot and water vapour, both of which are almost invariably present in fuel-fired ovens to the detriment of the finished appearance and lasting qualities of the stoved surface, are not produced in electric ovens.

As oxygen is necessary in the stoving process, modern electric ovens are generally equipped with a forced ventilating system, and in ovens of large sizes the air is washed and filtered before entering the oven, a distinct advantage when the highest finish is aimed at. Except in indirect fired ovens, the products of combustion released in any fuel-heated oven would counteract the advantage to be gained by washing and filtering the ventilating air, and ordinarily, therefore, no attempt is made to obtain a dustless atmosphere in such ovens.

Temperature control is of considerable importance, particularly where not only black but lighter colours also have to be stoved, and it is found in practice that enamelling ovens which are heated

electrically can automatically be controlled to within plus or minus one per cent. of any desired temperature.

The following are brief descriptions of some typical installations in this country:—

(*a*) In these works there are two ovens, each rated at 30 kW. and having dimensions of 8 ft. deep by 7 ft. wide by 6 ft. high.

The average load per oven is 500 light castings and pressed steel parts of average weight 2 lb. each, and the operation cycle is:—

1st coat ...	2 hours to heat up, then withdrawn.
2nd coat ...	2 hours to heat up, then held for 2 to 3 hours at 205°C.

The ovens are operated continuously for 24 hours per day, therefore approximately eight loads are put through each oven per day for alternately first and second coating.

These ovens are of the truck-loaded type, are forced-ventilated, have automatic temperature control, and have rising and falling doors at one end. The average daily consumption per oven is about 330 kWh.

(*b*) This installation consists of one oven with a loading of 15 kW. and having dimensions of 45 in. deep by 33 in. wide by 60 in. high. The usual load is 60 castings of average weight 15½ lb. each, and the average length of bake is three hours.

In this case temperature is controlled by hand at 205°C. The average daily consumption is 200 kWh.

(*c*) In this case there are two ovens each of 15 kW. with dimensions of 45 in. deep by 36 in. wide by 60 in. high. They are used for stoving sheet steel parts and castings up to 16 lb. weight. The average load is 1,400 lb. and the average length of bake is four hours.

The usual temperature is 177°C. and the average daily consumption is 330 kWh.

Varnish Making

The process of manufacturing varnish, such as is used in the making of printing inks, is fundamentally one of boiling pure linseed oil at a temperature of about 300°C., chemical reaction being caused by the passage of air over the surface of the hot oil, which results in a gradual thickening of the oil and ultimately in its becoming varnish.

The consistency of the varnish is controlled by regulating the boiling period, which varies with atmospheric conditions and for different grades of varnish. Thus for a thin varnish, boiling for from 6 to 9 hours at a temperature of 300°C. is necessary, whilst

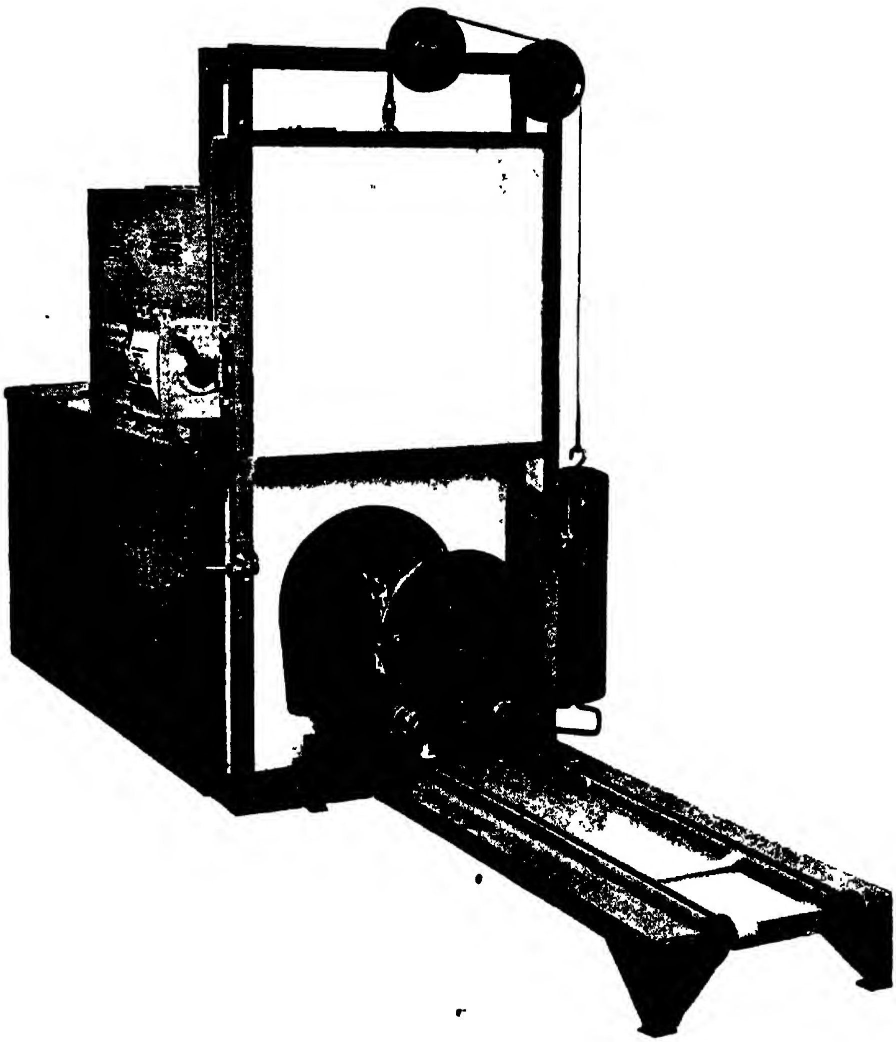

Fig. 2—Electric Furnace used for Rust Proofing of small steel parts.

for medium varnish about 13 hours at the same temperature is required; heavy and extra heavy varnishes need much longer boiling periods.

The question of close temperature control is one which has an important bearing upon the safety of operation of this process of boiling, as the flash point of linseed oil is only slightly above 315°C., and it is the demand for increased safety that has led to the adoption of electric heating in the process of varnish making.

In a recent installation, approximately 750 lb. of oil is contained in an aluminium boiler having a rating of 24 kW., the heating elements occupying a position underneath the boiler which, together with the heaters, is encased in a sheet of steel casing insulated with about 6 in. of high-grade heat-insulating material.

The temperature is controlled automatically, and by supplying an automatic time switch the current is switched on to the boiler at 2 a.m., the oil having been loaded into the boiler during the previous afternoon. By this means the oil reaches a temperature of 300°C. by the time the works open at 7.45 a.m., and boiling is continued at this temperature until the varnish is ready.

By using this cycle of operation, the bulk of the electric consumption takes place during the night hours, and, therefore, at the most economical rate.

Glass Annealing

Having regard to the importance of the glass industry, it is felt that this paper would not be complete without a short reference to this subject.

Unfortunately, no figures are available as to the cost of operating this process electrically under normal working conditions.

It might be stated, however, that by taking advantage of the close temperature control which is possible when using an electrically-heated furnace, the cooling cycle can be made to correspond very closely to the curve which is found to produce glass free from internal stresses.

II.—PROCESSES MAKING USE OF TEMPERATURES BETWEEN 500°C. AND 1,000°C.

Hardening, Carburising and Annealing Steel

Scientific heat treatment is less than twenty-eight years old, and prior to that, heat treatment operations were performed by rule of thumb methods. It was known that with suitable heat treatment steel could be softened, and likewise it was known that by suitable

heat treatment, followed by immersion in water or oil, steel could be hardened. There was knowledge also that by packing a low carbon steel in charcoal, and by heating this product for a sufficient time at a suitable temperature, it was possible to convert the soft ductile steel into a stronger and harder product.

Heat treatment has now developed into an exact science; for to-day, with a knowledge of cooling curves and constitutional diagrams, the properties obtained in metals after heat treatment can be predicted with considerable accuracy. It is true to-day that the growing demand for a higher quality in heat treated steels, and for a constant improvement of the physical properties of the metal, is making the electric furnace a commercial necessity, both in the manufacture of the metal and its heat treatment.

In working steels it is very important that they should be properly heat treated, as poor workmanship in this regard will produce working parts that are not good, even though the stock used be of the highest grade of steel that is procurable. All steels are improved in tensile strength, elastic limit, elongation, reduction of area, hardness and impact value by the processes of annealing, hardening or tempering.

The different heat treatments are divided into three distinct classes, the first of which is hardening, the second annealing or re-heating, and the third case-hardening, carburising or cementing.

The process of heat treatment of steel requires very careful control of temperature, as the resulting properties obtained in the steel are almost entirely dependent on the temperature at which the steel is hardened, tempered, annealed, or case-hardened. This control of temperature in the electric furnace is automatic, so that the undesirable human element is eliminated, thereby making the operation of heat treating steel a scientific process, and at the same time a practical one.

It may be safely asserted that the most important tool in the hand of the heat treater is his furnace, though it is one which, until recent times, has received very little consideration. Certainly there are no factors which assist him to greater degree than good furnace construction and automatic operation and control, and it is for this reason that electric furnaces for heat treating are rapidly being adopted. Some of the outstanding reasons for this are as follows:—

(1) Absolute control of temperature.

Not only is control positive and accurate, but the temperature is the same throughout the entire volume of

the effective heating chamber, giving heat by uniform radiation rather than by cyclonic blasts of gases. Varying weather conditions causing fluctuations in chimney stack pull make control of a combustion furnace difficult especially at low temperatures, where the temperature of combustion is far in excess of that required for the work. No such difficulty exists with electric heating.

(2) Improvement in the quality of the products.
- (*a*) Uniform rate of heat absorption eliminates distortion of long parts.
- (*b*) Temperature, rate of heating, and heating time being absolutely under control, results are duplicated day after day with precision.
- (*c*) Almost entire elimination of scaling and pitting, enabling subsequent operations to be better carried out.
- (*d*) Entire absence of deleterious furnace gases.
- (*e*) Less scrap and fewer re-treatments.

(3) Low labour costs.

(4) Cleanliness and better working conditions.

(5) Smaller working space for equal output.

(6) Starting-up delays eliminated.

With the combination of automatic temperature control and time switch equipment, numerous operations and the usual week-end stoppages and starts can be completed without supervision, thereby eliminating expensive week-end labour.

(7) High load factor and power factor.

Power can be consequently purchased at the cheapest possible rate.

(8) Low maintenance cost.

With electric heating repairs are almost negligible. The temperature of the refractories never exceeds the working temperature; while in a combustion furnace the materials are in direct contact with incandescent flame, which makes frequent repairs essential.

(9) Improved layout of shop.

An electric furnace does not require flues or chimney stacks and may, therefore, be situated just where it should be, namely, in the direct line of production.

(10) No annealing boxes.

Electric annealing of metals dispenses with annealing boxes, thus eliminating the initial cost and maintenance of the boxes and reducing the total mass of charge to be heated up.

Electric furnaces may be classified according to the design and manner of operation. There are:—

(*a*) The box furnace which is shaped as its name indicates and has a door at one end, and is usually loaded and unloaded by hand.

(*b*) The rotary hearth furnace which is round and so designed that the bottom moves slowly at a speed that can be controlled by the operator; the work—small parts such as gears, etc.—being fed in at one door and removed from an adjacent one after remaining in the furnace for the length of time of one revolution of the hearth. One man can handle such a furnace without assistance.

(*c*) The car bottom type of furnace which is arranged so that the bottom is a platform mounted on wheels forming a sort of conveyer. This type of furnace, in which the speed of charging and discharging is rapid, is generally constructed so that the hot charge coming out is passed into a chamber containing a cold charge, thereby making use of the heat from the work for pre-heating the cold material.

In many cases both the heating and the quenching are automatically controlled.

For hardening and tempering purposes, the electric furnace used is generally of the box type, although furnaces with rotary hearths are also employed, as this type permits of continuous operation with very little loss of heat. In furnaces of the box type, the heating units or elements are placed uniformly around the furnace so that even heat distribution is obtained, and for the reason that the heating elements on both sides of the hearth ensure a much more uniform temperature across the furnace, a wider hearth can be used than with ordinary fuel-fired furnaces.

For annealing purposes, it is usual to employ the type of furnace where the hot charge coming out passes into a cooling chamber and heats up the cold charge. This means that no hot material is handled by the operators, and no hot boxes are stored in the annealing room. One operator can charge into and discharge from such a furnace in a very short space of time, and it is possible to

do away with the usual annealing box and all the necessary labour involved in packing and unpacking. Naturally there is an appreciable and direct saving by avoiding the heating up of these boxes.[1]

The process of carburising can be reduced to an absolute time cycle by using either the rotary hearth or the car bottom type of furnace, as by running the charging end at a higher temperature than the remainder of the furnace the time occupied in heating the boxes can be hastened, without danger of overheating their contents; by this means approximately one and a half hours have been saved in the cycle in some installations that are at work.

The elements used in modern electric furnaces have reached a state of great reliability, and there is now no difficulty in obtaining from them, with a properly designed and operated furnace, a life of four to five years or longer.

Firing Colours on Pottery

In the manufacture of china and earthenware, readily fusible enamels are used for decorating the ware on the glaze. They are applied as lithographs, prints from an engraved copper plate, aerographed, or painted by hand, gold being applied as an amalgam or as "liquid gold." After being decorated in this way, the ware has to be heated to a temperature of 700°C. to 850°C., in order to fuse the enamels and render them adherent to the glaze, which, having been previously fired at about 1,100°C., does not fuse at the lower temperature of the enamel fire though it softens and helps the enamels to adhere.

The reaction of fusing the enamels, like most pottery reactions, depends upon time and temperature, and very accurate control of both is essential if the best results are to be obtained. In addition, it is essential that the atmosphere in which the ware is fired must be oxidising and free from water vapour and sulphates, in order that the inevitable dulling of the glaze and the enamels may be prevented. There must be provision also for releasing the oils, etc., which are used in applying the colours to the ware, as these are volatilised in the early stages of firing

A typical coal-fired "enamel kiln" consists of a box built of fireclay quarries about 2½ in. thick, which measures about 10 ft. long by

[1]A recent development in regard to electric annealing is of interest. This method is mainly applicable to stock of the same cross section, and it consists in passing electric current through the material, and because of the heat developed as a result of the resistance which the material offers to the passage of the electric current, the metal becomes annealed. The metal can be so treated that each of the pieces has substantially the same degree of temper, and there is a wonderful uniformity in the grain size of the metal.

4 ft. wide by 6 ft. high, and has an arched top and an open front. In operation it is packed with ware placed on suitable fireclay supports, and the front is closed with a "brick clamming" or fireclay door. Fireplaces underneath provide the heat and the flames, and hot gases which do not reach the goods circulate round the fireclay box in flues.

For each firing these kilns or muffles consume 20 to 25 cwt. of coal, and at the end of the firing not only the heat contained in the ware but the heat in the kiln structure is lost. The process, therefore, is very inefficient, as only a small portion of the heat content of the coal is utilised, probably less than 2 per cent. Apart from this inefficiency there are the further objections that, owing to the high temperatures, firebrick of high-grade has to be used in the construction of the kilns, and frequent repairs are necessary to these and to the inner lining.

Continuous coal-fired kilns, in which the ware moves on a travelling iron platform through a fixed fire zone, are economical from a fuel point of view, but are costly in repairs, and for the reason that the temperature control is not sufficiently accurate for high quality wares, they are generally only used for the treatment of ware of the cheaper classes.

Firing enamels on glazed pottery at a temperature up to 850°C. is now being successfully performed in kilns of the Electric Tunnel type, through which trucks are mechanically moved on rails at a speed varying from 3 ft. to 6 ft. per hour, according to the class of ware to be fired.

The heating elements are so arranged that the goods moving down the tunnel are gradually warmed to the requisite temperature, the hottest part of the tunnel being approximately at its centre.

For ventilation purposes provision is made for a slow current of air to move against the travel of the goods. Since the trucks increase in temperature as they travel along the tunnel, heat flows from the hotter to the cooler trucks, and due to this, and the current of air, a regenerative effect is obtained from the hot trucks as they leave the centre zone. It has been found in practice that the heat so obtained is sufficient to balance the heat lost through the walls of the tunnel.

The temperature of the electric kiln is regulated automatically and can be controlled at individual heights of the truck. This is a great advantage in pottery colour firing, as it is impossible to fire all colours at the same temperature. Practical experience with these furnaces shows that the ware treated in them is bright and glossy,

and that no dulling of the glaze of enamels ever occurs, and once the correct temperatures have been established they can be repeated with absolute precision.

Investigation into the actual cost of operating these electric furnaces under normal working conditions, shows that the cost of current is about half what the previous coal cost was in the same factories, and the labour costs are also less, due to the amount of work eliminated.

ANNEALING OF BRASS AND OTHER NON-FERROUS METALS

There are several electric furnace installations working in Great Britain for annealing non-ferrous metals, for which purpose the electrically-heated furnace offers certain outstanding advantages over the fuel furnace.

They can be of the ordinary box type, in which it is usually found sufficient to rely upon the human element for the timing of the treatment, or of the type in which the material is conveyed through the furnace by mechanical means, which is the best method of ensuring equality of treatment, though it is only possible where large quantities of material of the same type and quality are being dealt with, a condition not so frequently met as that in which the size, gauge, weight, and even composition are constantly changing.

Furnaces have been built to anneal non-ferrous wire by winding it continuously through the furnace, and in these, by the use of water seals and an inert atmosphere, it has become possible to produce the wire in a bright state.

A number of furnaces are now in operation in the Midlands and other parts of the country, which are used for annealing brass, copper, nickel silver and other nickel alloys. In one case the furnace is for annealing brass, and the heat losses at 650°C. are under 10 kW. When running continuously the consumption is approximately 100 kWh. per ton, this consumption rising to 110 kWh. per ton when the furnace is in use during the day only.

This installation has been at work about two years and has not required either replacements or repairs. Certainly the cost of current is greater than the previous cost of coke for the fuel furnace, but it has proved in practice to be economically superior by reason of the improved quality of the product and the certainty with which a given quality and quantity of output is obtained, and also by the elimination of the human factor.

A similar but smaller furnace has been in use for over three years, annealing nickel copper and nickel chromium alloys, usually taking the form of wire coils. This furnace has a rating of 52 kW., and the

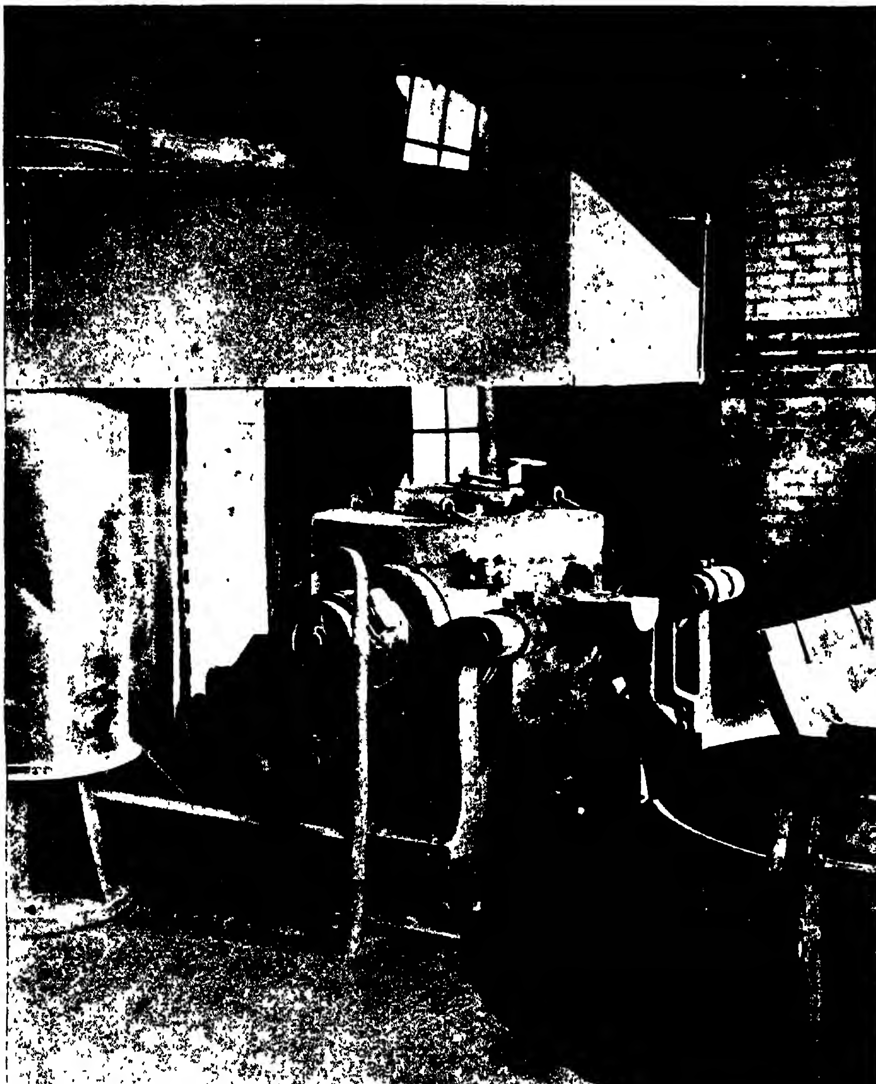

Fig 3—A 75-KVA. Brass Melting Furnace.

consumption when annealing nickel alloys at 900°C. is approximately 200 kWh. per ton, but this varies according to the period of "soak" allowed. In this case the more complete and more even annealing obtained had the effect of reducing the cost of subsequent operations sufficiently to pay for the furnace installation in less than one year.

Another installation, having a larger furnace of the recuperative type with a heat exchange chamber, is rated at 76 kW. In this the hot charges on leaving the furnace are placed into the recuperative chamber side by side with a cold, untreated charge, and as a result the ingoing charge is pre-heated to at least one-third of the final temperature, with a corresponding saving in the electrical energy required. The approximate consumption of this furnace is 140 kWh. per ton.

For the annealing of non-ferrous metals the electric furnace is ideal, its principal advantages being:—

(*a*) Evenness of temperature throughout the furnace.

(*b*) Constancy of temperature obtained by automatic control.

(*c*) Clean furnace atmosphere free from injurious gases, fumes or dust.

(*d*) Clean and comfortable working conditions.

(*e*) Owing to the free play of radiation in the pure atmosphere the variations in temperature from one part to another in a well-designed electric furnace are extremely small, whether the furnace is "idling" or running under full load.

These are all points of considerable importance in annealing.

In the annealing of nickel and nickel alloys, the pure atmosphere is a vital factor as nickel is particularly susceptible to sulphur.

Electro-Magnetic Hardening of Steel

It is an accepted fact that the finer, *i.e.*, the smaller the grain structure, the greater is the strength, toughness and resistance to wear of hardened steel, and the process of correctly hardening all steel consists in heating it to exactly the right degree, so as to obtain the finest grain size, and of then fixing as a permanent structure this altered arrangement of the molecules by quenching the steel in water or oil.

How to heat to the right degree is a fundamental question, as the consequences of not quenching at the right moment are extremely serious and are revealed in reduced wearing life, cracking, loss of toughness, etc.

Overheating produces not only a coarsening of the grain but also an excessive decomposition of the cementite into iron and graphite,

with a consequent reduction in strength and durability, and it often causes distortion and cracking. Faults arising from overheating are very prevalent and are difficult to detect by examination, as overheated steel appears hard to a file or to a hardness testing machine, none of the damage appears on the surface, and it is only later that the effects which inevitably result from overheating become apparent.

Underheating, on the other hand, is accompanied by the development of soft spots and general irregularity of structure.

If the problem were merely one of heating the steel to a critical temperature, varying according to the carbon or alloy content but, always constant for the same analysis, no great difficulty would arise. In practice, however, those convenient "critical" temperatures do not remain constant, but instead, the correct quenching temperature varies not only with the nature and analysis of the steel, but also with the rate of heating and the period during which the charge remains in the furnace.

By way of illustration, the variation in temperature which may be expected when treating 1·4 carbon steel, is shown by the accompanying curves in Fig. 4, and it should be explained that the samples were cut from the same stock, and in order to secure accuracy of temperature measurement, the couple of a pyrometer was immersed in the steel.

It will be noticed, that in the case of these two samples, the correct hardening temperature varied by approximately 50°C. and it is for this reason that hardening by temperature measurement alone is necessarily unreliable and leads to unequal and imperfect results. In general it is found where the pyrometer is relied on that the work is overheated, therefore resort must be had by other means of control if consistently accurate results are to be secured.

The passage of heated steel through the so-called "critical range" is accompanied by:--

(*a*) The absorption of heat.

(*b*) The loss of previously induced magnetism; and as both phenomena directly result from the physical changes ocurring within the steel, the completion of which it is essential to record, the correct indication of either offers a safe guide to follow as an alternative to the pyrometer method.

Properly hardened steel must be quenched exactly at the moment the necessary cementitic distribution has been secured, and if quenching is delayed or takes place too soon, the hardening will be

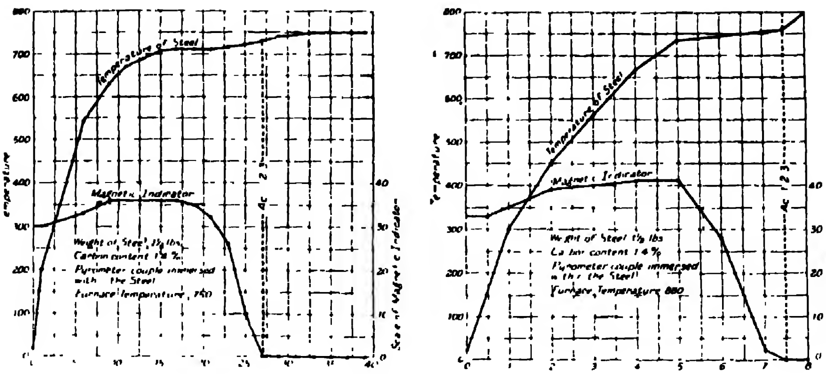

Fig 4.—Curves showing the variation in temperature at the critical point in steel heating.

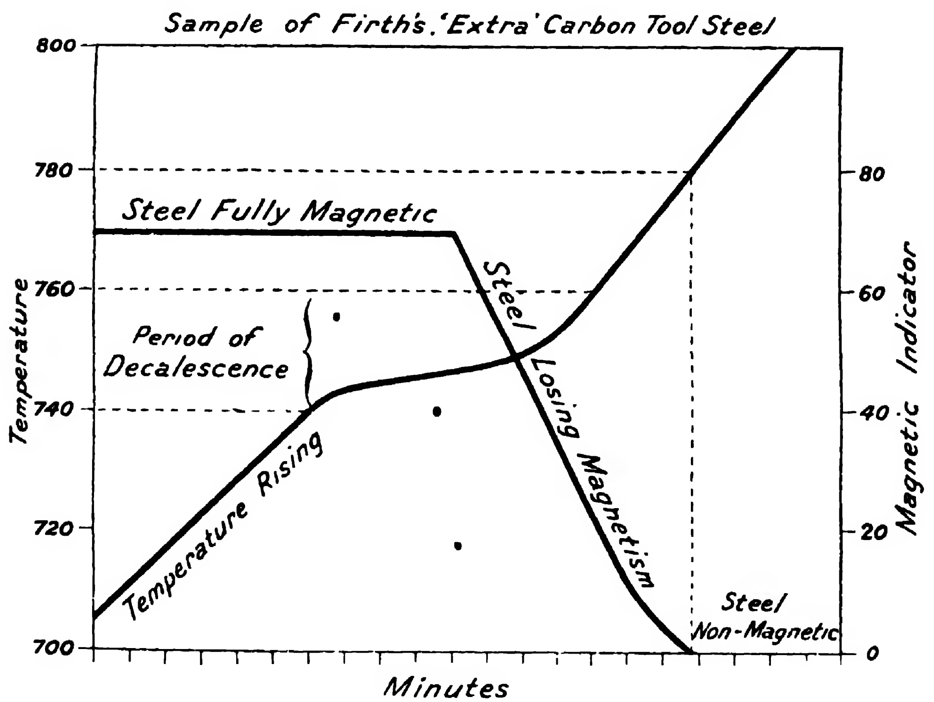

Fig. 5.—Graph showing the magnetic properties of steel and the temperature during heating.

indifferent; therefore, it is essential to provide a clear and definite indication of the exact moment that the changes in the structure are completed.

It is difficult, either by the use of a recording pyrometer or otherwise, to secure this by an indication of the absorption of heat by the steel. Hence the other phenomena referred to, namely the loss of previously induced magnetism, has been made use of and is now extensively employed.

In the year 1897, Roberts Austen showed that for steels containing ·4 per cent. or more carbon, the correct quenching point for hardening was that at which the steel ceased to be magnetic, and his so-called equilibrium diagram showed three critical points on the heating curve:—

A.C. 1 the point at which the solid solution commences.

A.C. 2 the point where the loss of magnetism occurs.

A.C. 3 the point where the diffusion of cementite is complete and the piece is ready for quenching.

It was also shown by Roberts Austin, confirmed by K. Honda and others, and is now a matter of common knowledge, that for steels of more than ·4 per cent. carbon the points A.C.2 and 3 coincide, and for steels of more than ·9 per cent. carbon the points A.C.1, 2 and 3 all fall together.

Thus for all such steels (and they comprise all commercial steels) an indication of the A.C.2 or non-magnetic point is also an indication of the A.C.3 or correct quenching point; and in the graph in Fig. 5 the time hardening point is directly indicated by recording the point at which the steel becomes entirely non-magnetic.

Furnaces operating on this principle are now widely used in this country, and so far as is known they provide, at the present time, the only method by which a definite and unmistakable indication of the correct hardening point can be completely secured when working under practical conditions.

III. — PROCESSES MAKING USE OF TEMPERATURES ABOVE 1,000°C.

Arc Furnaces for (a) Steel Making, or (b) Melting Cast Iron

The electric arc furnace for steel manufacture has been used commercially in this country for about eighteen years, induction furnaces having been introduced a year or two earlier; furnaces of the latter type, however, were not found satisfactory, principally because it was necessary to leave sufficient molten metal in the furnace after

each heat to start the next, and as the analyses required for high-grade steel are very numerous, this was a fatal objection.

The arc furnace, which did not have this disadvantage, was found to be a very efficient refining furnace, as by its use sulphur and phosphorus contents are reduced to very low figures. Accordingly, cheaper scrap could be used than in the case of the crucible process, and this factor, together with greatly reduced labour costs, made it at once a serious competitor of the crucible process. Several arc furnaces were installed in 1910, but their general adoption was not rapid until the outbreak of war in 1914, at which time the total amount of power employed in electric steel making in this country was about 4,500 kVA., with a potential output of about 22,000 tons per annum, though the actual output was probably considerably less.

By the end of 1918 the total number of furnaces under construction or in operation in Great Britain was about 140, with a total transformer capacity of about 115,000 kVA. About 70 per cent. of the production consisted of ingots and 30 per cent. of castings.

The steel made in these furnaces was, of course, required very largely for special war purposes, and upon the termination of hostilities it was difficult to find a use for a large proportion of the available capacity; therefore, a number of furnaces were sold to steel makers in the Dominions and others were closed down. Statistics are not available to show the present production of electric steel, but the figures are undoubtedly increasing again, and several new plants have recently been installed.

The steadily growing sale of stainless iron and steel has been one of the causes of this increase, and a considerable number of electric furnaces are also being employed in foundries and for the manufacture of alloy steels.

(A) Steel Making

For steel manufacture the electric arc furnace has the great advantage that it enables the operator to have complete control over all the chemical and physical conditions required to make high quality steel.

This is due to several causes such as:—

(1) The temperature is at all times completely under the control of the operator.

(2) Owing to the high temperature that can be obtained, a very basic or acid slag can be maintained in a fluid condition.

(3) Phosphorus and sulphur can be almost entirely removed.
(4) The charge can be held for any length of time before pouring without damaging the steel, if delay is necessary for any reason such as waiting for analysis, etc.
(5) The precise control of temperature makes it possible to cast the heat at exactly the right temperature.
(6) The violent motion of the metal produced by convection currents causes intense mixing, and also increases the rate of refining, as the part of the steel bath in contact with the slag is constantly being changed.
(7) A furnace can be worked with either a basic or an acid lining. The former has the advantage of refining, but the latter is quicker and consequently cheaper to operate, as only one slag is required instead of two, as in a basic furnace.
(8) The process is considerably cheaper than the crucible process.

(B) MELTING CAST IRON

Grey iron can be produced in the electric furnace by melting mild steel and adding carbon, but the economic possibility of this process depends on the relative cost of these materials and the cost of power in the one case, as against the cost of fuel and the cost of pig iron and scrap in the other. The quality of the product is undoubtedly very much higher than that of cupola iron, though in this country the cost is more, the cupola having the advantage if the scrap is of such purity that no refining is required.

There are certain cases where a higher price can be obtained for castings having a higher tensile strength and more uniformity, and in these the use of an electric furnace is an economic possibility, though the duplex process for making grey iron, by which metal is melted in the cupola and transferred to the electric furnace, is probably the most economical method of obtaining the highest grade of iron.

By this process the iron is melted in the cheapest manner, the cupola being, under British conditions, considerably more economical than the electric furnace, and is then super-heated electrically, so that the iron is more fluid than would otherwise be possible, while at the same time sulphur can be removed.

A considerable quantity of "semi-steel" is made by mixing cast iron and steel in the electric furnace, the material made being much more regular than that made in the cupola.

Arc furnaces are also being used in this country for the manufacture of nickel chrome and pure nickel, and the treatment of tin oxide.

LOW AND HIGH FREQUENCY FURNACES

(A) Low Frequency

As already stated, induction furnaces working at normal, or less than normal, frequencies were introduced into this country for making steel about twenty years ago, but they made no progress and induction heating remained stagnant until after the war. It is, theoretically, the ideal method of heating, as all the heat is generated in the metal itself, and there is no possible source of contamination of the metal by gases, as in the case of coke or gas-fired furnaces, or by electrodes as in an arc furnace, and there is a very complete mixing of the material by the electric forces.

The use of a vertical instead of a horizontal ring in America, and the application of this method of melting to brass caused an extraordinary development in the use of electric melting in this industry, and at the present time there are over 600 furnaces of this type in the world, with a total capacity of about 1,000,000 tons of brass a year.

In England thirty-three furnaces of a total capacity of 2,475 kVA. are now in operation.

The principal reasons for the rapid development of induction melting are:—

(*a*) The great saving in cost largely due to saving in labour, which is less than half that used in the crucible process.

(*b*) The high quality of metal manufactured.

(*c*) Considerable reduction in zinc losses.

(*d*) Much lower cost of lining than in the case of crucibles in the old process.

(*e*) Better working conditions than in a crucible plant, as there is no heavy labour and there is an absence of fumes and dirt.

(*f*) High load factor and power factor enabling power to be purchased cheaply.

It is generally found that the loss of zinc is at least 1 per cent. less than in a crucible furnace, while in some works this figure is greatly exceeded, and as a saving of 1 per cent., with spelter at £36 per ton, is equivalent to 7 shillings per ton of brass, it follows that this saving is appreciable.

Normal frequency induction heating has certain definite limitations, among these being the necessity of leaving part of the metal in

Fig 6.—A High-frequency Electric Furnace used for the manufacture of High Grade Tool Steel, showing the switchboard and turn-table for casting.

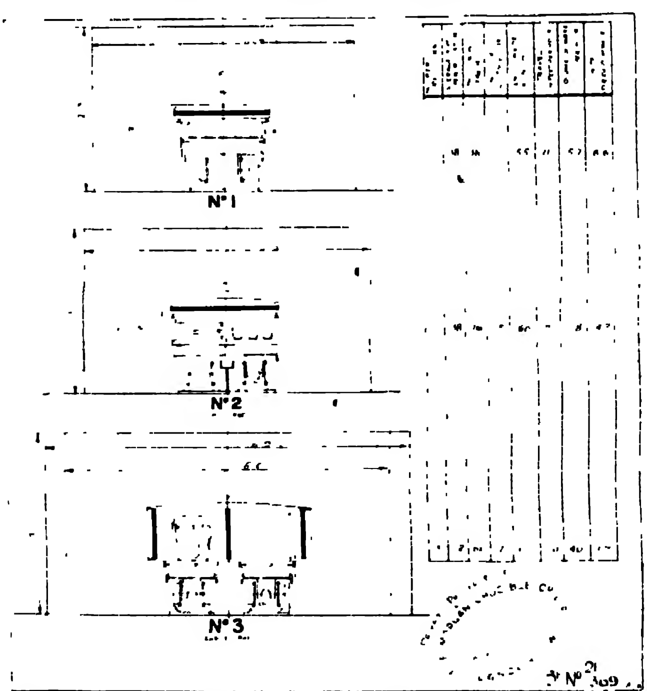

Fig. 7.—Three types of Electric Tunnel Kilns used for Glost Pottery.

the bath at the end of each heat in order to start the next heat, and for this reason the furnace is not suitable for making a large variety of alloys such as are required by the usual brass foundry. Further, it is essential that work should be more or less continuous during the week, as otherwise the cost of power required to maintain the metal in the slot in a molten condition while the furnace is not being used for melting, becomes excessive.

For ordinary brass melting the lining of the furnace lasts almost indefinitely, a number of cases being on record of furnaces being in operation three or more years without the linings being renewed, but for very high copper alloys, etc., a suitable lining has not yet been found.

(B) High Frequency

Accordingly, in cases where normal frequency melting is not suitable, it is necessary to resort to high-frequency melting. Small high-frequency sets using spark gap equipments to obtain current of suitable periodicity have been in operation for some years for melting platinum, for research and for the manufacture of silica ware.

The most important commercial plant of this type in the world was erected in this country and comprised forty-two furnaces, each of 35 kVA., which were used for the manufacture of Mumetal, an alloy of nickel, iron and other metals, several hundred tons of Mumetal of outstanding quality being so manufactured.

For obvious reasons, furnaces of the spark gap type are limited in size, 20 lb. of steel being the most that can be conveniently melted with one equipment, though two and three equipments have been used together to make two and three-phase furnaces. They were, however, not large enough to use for commercial steel making or other similar purposes.

This limitation led to the perfection of high-frequency motor generators, and the advance made in that direction has made possible the use of much larger furnaces than was hitherto practicable. Five of these furnaces are already at work in this country with a total generator capacity of 700 kW., and others are in course of construction.

High-frequency furnaces have many advantages over the normal frequency induction type, as the furnace can be completely emptied, and no metal need be left to start the next heat. Accordingly, the difficulties of dealing with a variety of alloys and the necessity of more or less continuous working, are overcome.

The equipment consists of a crucible surrounded by a coil, which may be either air or water-cooled. Insulating sand is placed between the coil and the crucible, and the whole is enclosed in a box which may be of wood or some other non-conducting material. The furnace may be tilted either by hand or by motor.

For making high-speed steel and similar steels now made in coke or gas-fired crucibles, high-frequency melting is ideal. It retains all the old advantages of the crucible process, and has several additional merits of great importance, namely:—

(*a*) The complete freedom from gases such as are inevitable with coke or gas-fired furnaces.

(*b*) The process is much cheaper owing to the great saving of time and labour. A 4-cwt. charge of high-speed steel can be melted in about an hour in a 150-kW. furnace, the power consumption, including all motor generator losses, being about 800 kWh. per ton, which is as low as can be obtained in a small arc furnace.

(*c*) There is a very complete mixing by electrical forces.

(*d*) The cleanliness of working and absence of heavy manual labour are most striking.

(*e*) The quality of the steel made in high-frequency furnaces is definitely better than that made in the old crucible process.[2]

Up to the present the largest furnace installed is equipped with a 200 kW. motor generator, but there is no reason why larger furnaces should not be installed, and probably furnaces of at least one ton capacity will be built before long.

Furnaces are also in operation for the manufacture of nickel, nickel silver and cupro-nickel, and other metals and alloys, such as aluminium, copper, nickel-chrome, brass, etc., have been successfully melted.

FIRING AND GLAZING POTTERY

"Glost" firing of domestic pottery such as cups, saucers, plates, soup tureens, vegetable dishes, etc., has to be carried out in great cleanliness, and as they are delicate they have to be supported in the furnace in such a way that one article does not touch another, otherwise the glaze, when hot, would cause them to adhere to each other. To fire a large quantity of these goods in one furnace they have to be packed in containers known as saggers.

In spite of the greatly improved fuel efficiency of continuous

[2]This has been proved under actual working conditions in this country.

kilns, the kiln most used in this country and America for "glost" firing china is a round kiln, which is worked periodically and is fired by coal, the saggers being stacked in it to a height of 16 ft. to 20 ft.

There are tunnel kilns in use which are very economical, but they require a very large space not often obtainable in our old pottery works, and further, they require a large output to keep the kilns occupied.

In these tunnels the travel of the trucks must be comparatively slow so that an even temperature is obtained throughout the ware loaded on it, as the heat is supplied by hot gases which always tend to rise to the top of the kiln, and the ware on the top heats quicker than the rest. To overcome these difficulties electrically heated tunnel kilns are now being used, and their more general adoption may be expected for the following reasons:—

(*a*) They can be made in small units and still be economical in use.

(*b*) The heat distribution is more uniform as the cross sectional area of the ware on the truck being small, each article comes near the source of heat.

(*c*) There is very little movement of gases in the kiln, and the heat from the resistors being chiefly radiant, there is little tendency for the top to be hotter than the bottom.

(*d*) The trucks in an electrical kiln can travel at least four times as fast as the trucks in a kiln heated by other means, say, 1 in. in three minutes, hence the cross sectional area of the kiln need only be one-quarter that of other kilns of the same output. This naturally results in a greatly reduced size and lower cost of kiln.

(*e*) When the kiln is small there is a considerable saving due to it being possible to stack the ware without the use of saggers.[3]

(*f*) The atmospheric conditions in an electric kiln are under perfect control and the atmosphere is clean.

(*g*) Due to the quick rate of firing in the electrical kiln, the colours under the glaze are clearer and sharper than in any other kiln.

"Glost" firing is carried out at temperatures from 1100°C. to 1200°C., and one of the chief difficulties experienced in the past in designing an electric furnace for this purpose was to obtain a resistor that could be built into the kiln in the position required, and which

[3]The weight of the saggers in most kilns is many times the weight of the ware fired.

would stand the high temperatures and at the same time give a commercial life; but many expensive experiments with electric kilns for the higher temperatures have been carried out on a large scale during the last few years, and suitable and reliable resistor elements are now obtainable.

Several electrically-fired kilns are in use, of which the following are examples:—

Kiln No. 1 was started up in 1915 and has been in continuous operation ever since. In this kiln the resistor, which is about 7 ft. long and 22 in. wide, forms the roof of the tunnel through which one line of trucks is passed. The space between the surface of the truck, and the roof of the tunnel is very small, being only 4 in. The kiln is, therefore, only suitable for firing small articles such as plates and cups and saucers. Cups which are difficult to stack in saggers are particularly suitable for this type of kiln; the heat efficiency, however, is not high.

Kiln No. 2 was started in 1926 and is of the same type as No. 1, but has a wider resistor (24 in.); two of these are used in making a total heat zone about 15 ft. long. Two lines of trucks are pushed through this kiln simultaneously in opposite directions, so that there is a regenerative action obtained, the hot trucks leaving the zone on either track, warming the cold trucks as they enter. This kiln has a much higher efficiency than Kiln No. 1 and is capable of "glost" firing a dozen cups per minute with a total loading on the two resistors of 70 kW., 35 kW., on each resistor.

Kilns of this type, being confined to firing cups and similar articles, are only economical when a very large output of this particular article is required.

Kiln No. 3 was started in 1927 and has a much higher efficiency. In this kiln, which is purposely of small dimensions, the resistors, instead of being in the roof, are arranged vertically, the centre resistors being fixed between two lines of trucks working in opposite directions, the others being fixed one in each outside wall. The trucks are only 12 in. wide and 5 ft. long, and ware can be stacked 12 in. high. Trucks have been fed through the kiln one every quarter of an hour on each track, giving a total of 8 trucks per hour, or a net cubic capacity of ware of 40 cu. ft. per hour, which works out a very little more than 1½ kWh. per cu. ft. of ware space.

The output of the various kilns can briefly be given as follows:—

Kiln No. 1 (approximately 55 ft. long).—Loading 40 kW. 7 cu. ft. of ware per hour. Consumption about 6 kWh. per cu. ft.

Kiln No. 2 (approximately 59 ft. long).—Loading 70 kW. One

dozen cups per minute or the equivalent of, say, 20 cu. ft. of ware per hour. Consumption about 3½ kWh. per cu. ft.

Kiln No. 3 (approximately 105 ft. long).—Loading 60 kW. About 48 dozen plates per hour or the equivalent of 40 cu. ft. of ware per hour. Consumption about 1½ kWh. per cu. ft. or 1·25 kWh. per dozen plates.

As these furnaces work at a load factor of about 90 per cent., with a power factor of unity, current can generally be obtained at very reasonable rates, and from these figures of consumption it will be seen that there is a decided saving over the coal used in periodic coal-fired kilns, quite apart from the saving in saggers, reduction in wages, and improvement in ware or saving in rejections.

High-Speed Steel Hardening

High-speed steel has the property of retaining its hardness up to a dull red temperature, which property is obtained by the addition of 14 to 18 per cent. of tungsten, and a smaller amount of chromium and sometimes other metals, and to obtain a complete dispersion of the tungsten throughout the mass of steel, heating up to a temperature of 1250°C. to 1300°C. is necessary.

This heating is carried out in two stages, and, for the reason that the steel, when cold, is a very poor heat conductor, it is necessary that the initial stage should be a process of slow heating. As to the second or finishing stage, the heating must be carried out very quickly, because if the atmosphere of the furnace is oxidising, both the carbon and tungsten are quickly burnt out of the steel. On the other hand, however, if the atmosphere is reducing, the steel takes up carbon and is converted into a sort of cast iron.

As a consequence, two furnaces are required for this hardening process of high-speed steel. One of these, which may be a nickel-chrome wound muffle, is used for the 700°C./800°C. heating, and the other, which is fitted with special high-temperature elements, usually of the carborundum type, is employed for the second, *i.e.* the 1300°C. stage.

In order that sufficiently quick action may be obtained, the heaters of the second furnace are so arranged that they run at a temperature of at least 100°C. above that which the steel must reach. It is therefore only possible to measure the temperature of the steel by use of an optical pyrometer.

On the completion of this heating the steel is allowed to cool down, after which, in order that it may acquire its property of retaining hardness, it is re-heated to a temperature of 600°C. to 625°C.

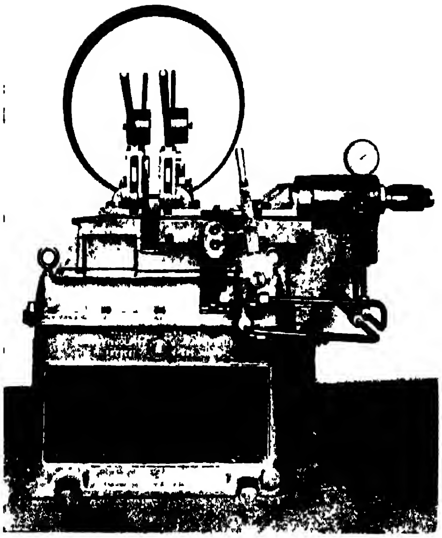

Fig. 8.—Butt Welding

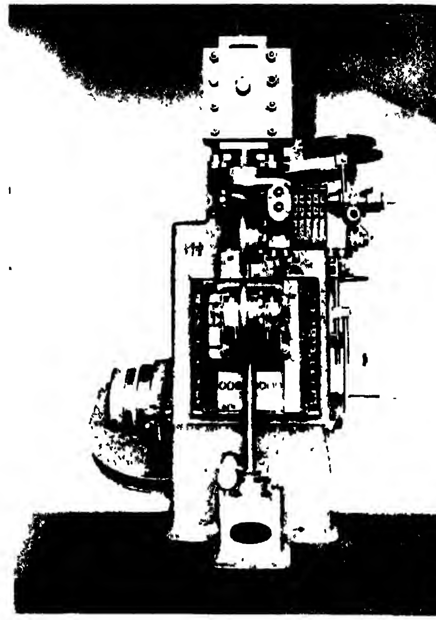

Fig. 9.—Seam Welding

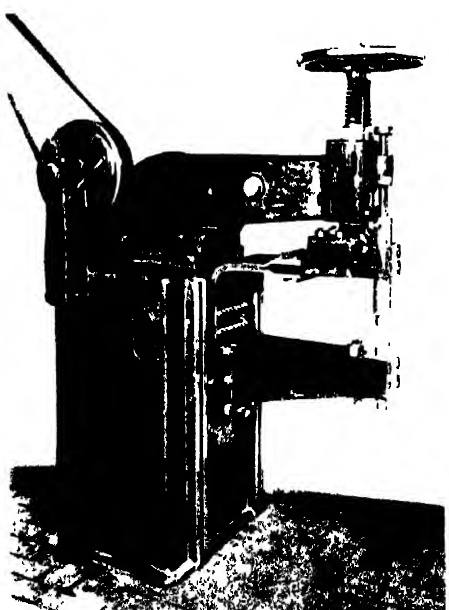

Fig. 10.—Spot Welding.

MISCELLANEOUS HEATING APPARATUS

Electric Resistance Welding

This system of welding has made great advances in recent years, and machines are now used for specialised purposes which result in a good demand for energy at a high load factor. By the use of resistance seam welders mild steel sheets up to $\frac{3}{8}$ in. added thickness, can be seam welded together and a gas and liquid-tight joint produced at a speed of 1 to 3 ft. per minute. One of the great advantages of this system is that it is fully automatic in so far that it does not require any special skill for its operation, and, therefore, the installation is not debarred when such skill is not available.

The greatest number of machines installed so far are for butt and spot welding, there being many butt welders in use which take 300 kW. to operate them, and it is highly probable that during the next few years there will be a very large increase in the number installed, as the use of these machines enables great economies to be effected; this is very noticeable in the production of parts which involve a large amount of machining, as it provides a means for welding together two or more simple parts which would be difficult and intricate to make as a whole.

The modern spot welder, which may be power driven, does not depend upon skill or the human element for the success of the weld, and works in a similar manner to a punching machine, but instead of making holes it makes solid metal between the two or more plates which are being welded. It will weld up to $\frac{3}{4}$ in. added thickness and takes 60 kW. to operate it; a machine of the power-driven type will make 720 spots per hour.

Rivet Heating

Rivet heating by electricity, already firmly established on the Continent, is fast gaining ground in this country.

The rivet heating machine operates upon an alternating current and consists substantially of a transformer, of which the secondary consists of a single turn developing an EMF. of from 1 V. to $2\frac{1}{2}$ V., and so arranged that the circuit is completed through two substantial copper blocks, one of which is movable.

The rivet to be heated is placed between these blocks and held in position by adjustment of the movable block. Each such transformer, complete with its secondary as described, is termed a "head," and machines are built with one, two or three heads as required.

The resistance offered by the rivet to the flow of the current is sufficient to raise it to the required temperature. The time taken

to heat a rivet is from 15 to 45 seconds, depending upon its diameter and length. Many distinct advantages are offered by this method of heating as compared to others, for instance:—

(*a*) The machine is always ready for use at a moment's notice.
(*b*) No preliminary heating is required.
(*c*) There are no fuel stocks to carry and no refuse to be disposed of.
(*d*) No burned or under-heated rivets and no leakage of fuel.
(*e*) The rivets are heated uniformly throughout, the heating proceeding from inwards outwards, a great advantage as compared with furnace-heated rivets, in which the skin is sometimes burned by overheating before the whole is at the right temperature.
(*f*) A maximum of portability.
(*g*) Improved labour conditions.
(*h*) Saving in labour, as one boy operating a three-head machine can supply heated rivets to two rivetting squads.

There should be at least four heating intensities obtained by tappings from the primary transformer windings brought to suitable switch contacts, and when operating with special types of rivets, such as those made from stainless steel, a finer degree of heat is required, for which purpose eight or ten tappings are provided.

No precise figures are available for comparison with gas or oil heaters, but users state that the cost of fuel consumed is about equal, whereas the above-stated advantages are in favour of the electric heating.

The following table shows the approximate consumption of electricity per thousand rivets:—

Size of Rivet in in. dia.		length		kWh.
$\frac{5}{8}$	×	$1\frac{7}{8}$	...	35·2
$\frac{5}{8}$	×	$2\frac{1}{4}$	...	38·4
$\frac{3}{4}$	×	2	...	60·0
$\frac{3}{4}$	×	$2\frac{1}{2}$	...	60·8
$\frac{3}{4}$	×	$2\frac{3}{4}$	...	72·0
1	×	5	...	300·0
$1\frac{1}{4}$	×	6	...	400·0

GENERAL

There are also numerous heating applications of the smaller types which are now operated electrically in the British Isles, common examples of these being:—

Solder baths; type metal melting; wax heating; galvanising; glue heating; oil heating; coffee roasting; fruit ripening; rubber vulcanising; type making; pleating; water distilling.

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Burns, Sydney, A M I.E E	14, Balmoral Gardens, Monkseaton, Northumberland.	Heating apparatus for large buildings.
Campbell, Arthur John	Oulton Cross, Stone, Staffs.	Firing colours on pottery
Crossley, James Horace, B.Sc. (Lon. Engineering), Wh. Ex.	Chez Nous, Moorside Road, Flixton, Manchester	Bread and confectionery baking. Enamel stoving
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ZUSAMMENFASSUNG

Dieser von der "British Electrical Development Association" (Britische Elektrizitätsentwicklungs-Vereinigung) vorgelegte Bericht trägt absichtlich einen nicht-technischen Charakter, und wurde nicht mit dem Vorsatz geschrieben, technische Beschreibungen in allen Einzelheiten auszuführen, sondern vielmehr, um einige der so verschiedenen und zahlreichen elektrischen Heizungsverfahren, wie sie in der britischen Industrie verwendet werden, zusammenzustellen.

Die irrtumliche Ansicht ist weit verbreitet, dass die Verwendung der Elektrizität zu industriellen Heizzwecken in Ländern ohne Wasserkräfte unwirtschaftlich und der Kohlenverbrauch infolge der Umwandlungsverluste im Vergleich zur erhaltenen Energie ubermässig hoch ist. Es wird anscheinend nicht genugend anerkannt, dass bei Verwendung von Elektrizität zu industriellen Heizzwecken ein grosser Prozentsatz nutzbringend verbraucht wird. Es kann geradezu gesagt werden, dass er in diesem Falle 100prozentig ist, während sich bei Untersuchung des Wirkungsgrades von Feuerungsanlagen herausstellt, dass nur ein geringer Prozentsatz der Wärmeenergie das gewünschte Ziel erreicht.

Die Tatsache, dass Elektrizität zu diesem Zweck in den britischen Inseln bereits in so grossem Masse verwendet wird, genügt um zu zeigen, dass diese Anwendungsmöglichkeit wirtschaftlich gerechtfertigt ist, immerhin wird nicht behauptet, sie sei in jedem Falle die ideale Heizmethode unter den englischen Verhältnissen

Es ist daher notwendig, die anzuwendende industrielle Heizmethode in jedem Fall einzeln zu entscheiden, und wir sind überzeugt, dass durch die Beschreibung einer Anzahl Anwendungsbeispiele elektrischer Heizung, die gegenwärtig unter wirtschaftlichen Verhältnissen in England arbeiten, dieser Bericht nicht nur dazu beitragen wird, den Unglauben an die wirtschaftlichen Entfaltungsmöglichkeiten der elektrischen Heizung zu entkräften, sondern auch als Führer dienen wird in Bezug auf die Zweckmässigkeit ihrer Anwendung im einzelnen Fall.

Beim Behandeln der in England gebräuchlichen elektrischen Heizverfahren unterscheidet dieser Bericht vier Gruppen von Apparaten, nämlich für—

(*a*) Vorgänge, bei denen Temperaturen unter 500°C zur Anwendung kommen.

(*b*) Vorgänge, bei denen Temperaturen von 500°C bis 1000°C zur Anwendung kommen.

(*c*) Vorgänge, bei denen Temperaturen über 1000°C zur Anwendung kommen.

(*d*) Verschiedenes.

Am Schluss gibt ein Anhang eine Übersicht uber die bei einigen der untersuchten Anlagen erhaltenen Resultate.

Der Bericht enthält die Beschreibung einer Anzahl von Heizungsverfahren, die elektrisch betrieben werden.

THE THERMAL EFFICIENCY OF AN INDUSTRIAL ELECTRIC FURNACE

POWER ASSOCIATION OF JAPAN

DR. TSUNEZO KAWASAKIYA

Paper No. K11

CONTENTS

In this paper, the author examines the problem of defining the thermal efficiency of an electric furnace used for bringing about some physical or chemical change by the application of heat. He then proposes a definition of rated thermal efficiency for incorporation in a standard specification for an industrial electric furnace.

Previous Attempts to Define Thermal Efficiency

At first sight, it would appear that the thermal efficiency of a furnace for heating purposes should be expressed as the ratio of the heat usefully employed to the total heat supplied, following the analogy of the "efficiency" of a machine. But the thermal efficiency, as thus defined, does not always mean the same thing when referred to by different designers and users of electric furnaces, on account of the ambiguity of the terms "useful heat" and "waste heat."

Thomson[1] defines the thermal efficiency of an electric furnace as follows:—"The efficiency of electric furnaces may be defined as the ratio of the heat actually used to heat the reacting substances to the required temperature and the heat absorbed by the reaction to

total heat supplied." Similar definitions are given by Allmand,[2] Stansfield,[3] and others. These are not entirely satisfactory, as Thomson admits, for in the case of furnaces used only for holding a charge at a temperature higher than that of the surroundings, the efficiencies of all such furnaces by this definition would be zero, and would, therefore, afford no basis for comparison. To avoid this difficulty Richards[4] introduces the term "generic" efficiency to connote the commercial meaning of the word, as opposed to the "specific" or technical efficiency.

The author is of opinion that the failure to express the specific thermal efficiency of heating furnaces in comprehensive terms, is due chiefly to want of sufficient consideration as to what constitutes useful and what waste heat. The distribution of the sum total of thermal energy supplied to an electric furnace is, therefore, examined, and a definition of thermal efficiency is deduced which takes into account all the heat lost in the complete operation.

Heat Energy Balance

The distribution of thermal energy in an electric furnace can best be reckoned up by a process of book-keeping, the various incoming and outgoing items for one complete operation being set down each in its proper column, as follows:—

Debit (energy supplied):—

- (*a*) Heat generated by conversion of electric power.
- (*b*) Heat stored in the charge and furnace walls at the commencement of the operation.
- (*c*) Heat received by the furnace during the operation from outside sources.
- (*d*) Heat evolved by exothermic reactions in the charge.

Credit (energy expended):—

- (*a*) Sensible heat absorbed by the products of the reaction.
- (*b*) Heat absorbed by endothermic reactions in the charge.
- (*c*) Heat stored in the furnace walls at the end of the operation.
- (*d*) Heat carried away by radiation and conduction to the atmosphere, etc.
- (*e*) Heat carried off by waste products.

Of the items on the credit side, heat absorbed by the endothermic reactions in the charge is clearly useful, whilst heat carried away by radiation and conduction to the surrounding atmosphere is clearly lost. The remaining items have to be considered as useful in some cases, and as lost in others, depending on the process and the

object to be attained. Whatever the use to which a furnace is put, the primary object is heating in some form or other; therefore, any heat unavoidably expended on this object must be reckoned as useful.

We can now proceed to analyse the thermal efficiency of an industrial furnace into two components:—

(i) Efficiency of storage of heat in the charge and furnace walls, etc.

(ii) The efficiency of contribution of heat to the charge.

In cases where the object of the process is to bring about some physical or chemical change, if the temperature applied is in excess of that necessary for the reaction, a third efficiency, which may be called "performance efficiency," must be introduced. Considered thus, the majority of heating operations are carried out at a very low efficiency as regards energy utilisation; their performance efficiency could be greatly improved by the substitution of some more suitable source of heat or by lowering the reaction temperature by the use of catalytic agents.

As the first component of the efficiency mentioned above is simply a measure of the maximum limit of energy available according to the laws of thermodynamics, it may be termed the "thermodynamic efficiency." The second component, depending as it does on the relative contribution of the available heat to the charge, may be termed the "relative contribution efficiency." We can, therefore, consider the overall efficiency of an industrial electric furnace as the product of a thermodynamic efficiency and several relative efficiencies.

Thermodynamic Efficiency and Relative Contribution Efficiency

Thermodynamic efficiency is thus defined as the ratio of the heat stored in the charge and furnace walls, etc., at the end of the heating operation, to the sum of the residual heat stored in the furnace at the commencement and that supplied from external sources during the operation. Relative contribution efficiency is the ratio of the heat contributed to the charge to the total heat stored in the charge and furnace walls, etc., at a specified temperature. The product of the two is the thermal efficiency of the furnace.

The thermal energy stored in a furnace[5] at any instant may be expressed approximately in terms of a single time element if a

variable "time constant" is assumed. The above definitions can then be stated in formulæ as follows:—

$$E_d = \frac{1}{e^{k} + \frac{1}{T_{ct}} \int_0^{t_1} f(t)\, dt} \quad \text{.....................(1)}$$

$$E_r = 1 - \frac{T_f}{T_{ct}} \quad \text{...(2)}$$

$$E = E_d E_t \quad \text{..(3)}$$

Where E_t =thermodynamic efficiency.

E_r =relative contribution efficiency.

E =thermal efficiency (overall).

e^{-k} =ratio of initial temperature to specified temperature (the "initial" and "specified" temperatures being measured from a standard "cold" temperature as zero).

$f(t)$ =electric or chemical power converted into thermal current, in terms of the steady flow of heat at a specified temperature, as a function of time.

t_1 =time required to complete the operation.

T_{ct} =apparent equivalent "time constant" of furnace and charge for the temperature specified.

T_f =apparent "time constant" of furnace alone for the temperature specified.

In the special case where $f(t)$ is a constant, say m, the equation (1) becomes:—

$$E_d = \frac{\quad}{e^{-k} + m \log_e \frac{\quad}{m - 1}} \quad (4)$$

The thermodynamic efficiency, as expressed in equation (1), depends upon the ratio of the initial temperature to the specified temperature, upon the rate of supply of electric power, and upon the apparent time constant of the furnace and charge.

In Fig. 1 have been plotted thermodynamic efficiencies for various rates of supply of heating power (assumed constant throughout the operation under consideration), *i.e.*, for various values of m.

The four curves marked 0, 5, 7 and 9, correspond respectively to the values for the ratio e^{-k} of 0, ·5, ·7 and ·9. Hence each curve shows the variation of efficiency with rate of power supply for a constant ratio of the initial to the specified temperature. These curves demonstrate clearly that thermodynamic efficiency increases rapidly with the increase in heating current m, whilst m is comparatively small but this increase has less effect on the efficiency for higher values of m.

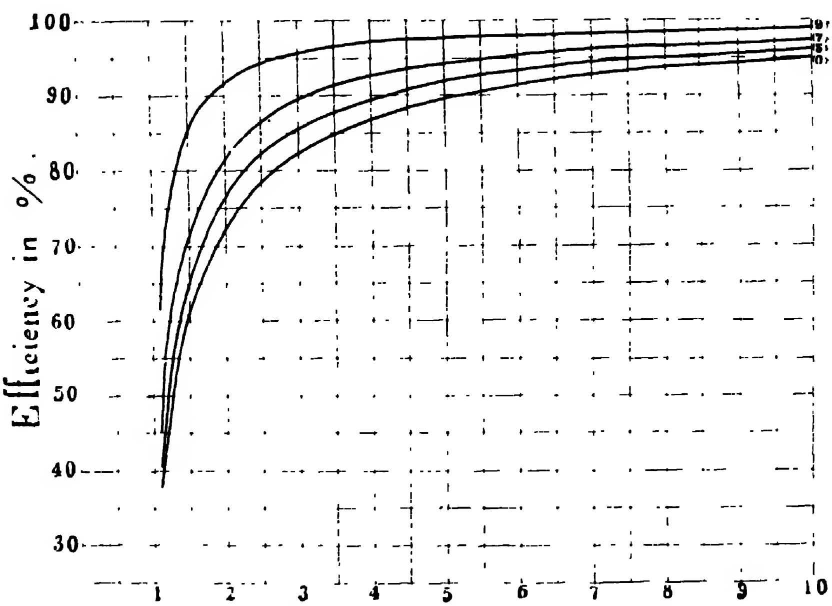

Fig. 1

THERMAL EFFICIENCY RATING.

The ratio (e^{-k}) of initial to specified temperature, is not an inherent characteristic of a furnace, nor, in general, is the rate ($f(t)$) of supply of energy; both may be varied by the operator to suit the work in hand. For purposes of comparison it is not practicable to take into account all possible variations, the better method being to specify standard conditions under which the rated efficiency shall be measured. The standard conditions proposed are, that the furnace, with a charge of known apparent time constant, shall be heated by supplying electric power at a constant rate from "dead cold" up to the specified temperature (this temperature not being maintained). That is, e^{-k} is zero, m is constant, and the temperature at which T_f

and T_{cf} are measured is specified. The formula for the thermal efficiency of the furnace then becomes:—

$$E = \frac{1 - \dfrac{T_f}{T_{cf}}}{m \log_e \dfrac{m}{m-1}} \qquad \text{.............................} \quad (5)$$

CONCLUSION

The overall thermal efficiency of an electric furnace is thus divided into two factors, the one depending on the established laws of thermodynamics, and the other on the transfer of heat. It is, therefore, possible to determine the maximum attainable limit of thermal efficiency under any conditions. Standard conditions are proposed for the rating and comparison efficiencies, which shall cover all cases of industrial electric furnaces.

The method of treatment adopted in this paper may be similarly applied to fuel burning furnaces except that an "energy conversion efficiency" must be introduced. This factor is unity for an electric furnace as the whole of the energy available is converted into heat.

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ZUSAMMENFASSUNG

Diese Abhandlung bezweckt die Definition des Thermischen Wirkungsgrades von elektrischen Öfen für Industrieheizung und schlagt die Definition eines Nenn-Warme-Wirkungsgrades vor als Teil einer Normal-Spezifikation. Ein typisches Beispiel fruherer Definitionen wird gegeben, um die Aufmerksamkeit der Leser auf die Inkonsequenz zu lenken, welche vielleicht durch den Mangel an Verallgemeinerung in der Auffassung der Nutzwarme und Verlustwärme

verursacht wurde. Der Verfasser schlägt vor, die gesamte Energie in einem elektrischen Ofen auf besondere Konten zu buchen wie in einer Buchhaltung, und stellt fest, dass der Heizprozess an erster Stelle zu erfassen ist, da er unumgänglich notwendig ist. Aus diesem Grunde kann der Thermische Wirkungsgrad eines elektrischen Ofens für Industrieheizung in zwei ganz bestimmte Wirkungsgrade aufgeteilt werden, nämlich den thermodynamischen Wirkungsgrad und den relativen Beitrags-Wirkungsgrad. Diese Wirkungsgrade werden in Worten und Formeln erklärt und eine Figur zeigt den Einfluss des anfänglichen Temperaturanstieges und der zugeführten Elektrizität auf den Thermodynamischen Wirkungsgrad. Zum Schluss schlägt der Verfasser Normal-Bedingungen vor, unter denen der Nenn-Wärme-Wirkungsgrad in Verkaufsgarantien für elektrische Industrieheizofen angegeben werden sollte. Die obige Betrachtung kann in ähnlicher Weise auf Öfen mit Brennstoffheizung angewendet werden, sofern ein Energie-Umwandlungs-Wirkungsgrad eingeführt wird.

THE APPLICATION OF ELECTRICITY TO THE FIRING OF ENAMELS ON PORCELAIN

JAPANESE NATIONAL COMMITTEE, WORLD POWER CONFERENCE

YASUZAEMON MATSUNAGA

Paper No. K12

CONTENTS

Introduction of the Electric Kiln in Japan

The tendency of modern industry to favour electricity as the source of energy is due to the fact that electricity can not only save human labour, but also economise fuel. It improves the quality and increases the quantity of the goods produced when it is used for heating and motive power The prices of goods are consequently reduced, enabling producers to meet the competition of other nations. The process of firing the colours, or enamels, on porcelain furnishes an example of this.

Pine wood fuel was almost the only source of heating for this purpose in this country until electric kilns came into use. The engineers of the Nagoya branch of the Toho Electric Power Co. Ltd. (Toho Denryoku Kabushiki Kaisha), having seen the advantages of electrifying porcelain makers' kilns, initiated, in March 1923, a campaign of education among porcelain makers in the district. About this time, Mr. Tatsusaburo Odake, who is an authority in the porcelain industry, also favoured the electrification of the porcelain maker's kiln; and an electric kiln of 2 kW. capacity, made in this country, was put under test. The result was rather unsatisfactory, owing to the unfamiliarity of the workmen with its operation and to the difficulty experienced in keeping a uniform temperature in

the kiln. In February of the following year a second test was carried out with another electric kiln of 12 kW. capacity, which was borrowed through the courtesy of Seki Hamano Seizo Kaisha. This time the result proved fairly satisfactory. Mr. Odake therefore induced the Naigai Dennetsuki Kaisha to construct an experimental kiln rated at 40 kW., 100 V. This had a capacity of ·5 cubic metres, and was square in shape.

After a series of tests the difficulty of controlling the temperature was overcome, thus enabling goods of fine quality to be fired. Some doubt still remained as to the practical use of the kiln, because of its high price and of the uncertain life of the wire in the heating elements. The example of the gas kiln, which had proved a failure a year previously, also made manufacturers afraid of a similar experience with the electric kiln. However, the Seiei Co. Ltd. tried a test in April 1925, with a cylindrical kiln of ·780 cubic metre capacity, for 50 kW. at 200 V., made by the Chubu Electric Manufacturing Co. Having obtained a very good result, the company at once installed sixteen similar units, totalling 800 kW.

In February 1926, Mr. Odake ordered from the Dai-Osaka Dennetsuki Kaisha a square kiln to his own designs (Fig. 1). As this proved satisfactory and simple several others were constructed, various improvements being added which tended to reduce the cost. The present price of a 50 kW. kiln of this type is about 1,050 *yen* (£105).

The Chubu Co. about the same time designed another type of electric kiln, similar to those constructed for burning wood. A test proved that the energy consumption of this type was from 20 to 30 per cent. less than that of any other. The cost of one of these kilns, having an internal diameter of 106 cm., is about 380 *yen*, and that of another, 121 cm. in diameter, 540 *yen*. Since the Toho Electric Power Co. introduced this new type of electric kiln in Nagoya in 1923, a careful analysis has shown that the quality of porcelain colouring is improved considerably when the firing is carried out electrically, apart from the advantages of economy and simplicity. Other districts, such as Yokkaichi, Kanazawa, and Saga, have followed the example of Nagoya, and the use of electric kilns is now spreading.

According to investigations of the Department of Commerce and Industry of the Japanese Government, porcelain ware to the value of 61,287,274 *yen* (£6,100,000) was produced in the seven prefectures of Aichi, Gifu, Saga, Kyoto, Mie, Ishikawa and Fukuoka. Exports

of porcelain during 1926 amounted to approximately 33,000,000 *yen* (£3,300,000) in value, which corresponds to 1·1 per cent. of the total export trade of Japan. The porcelain industry in 1925 was carried on by 1,948 manufacturers, owning 2,394 kilns (of which 570 were for enamel firing) and gave employment to 16,447 persons.

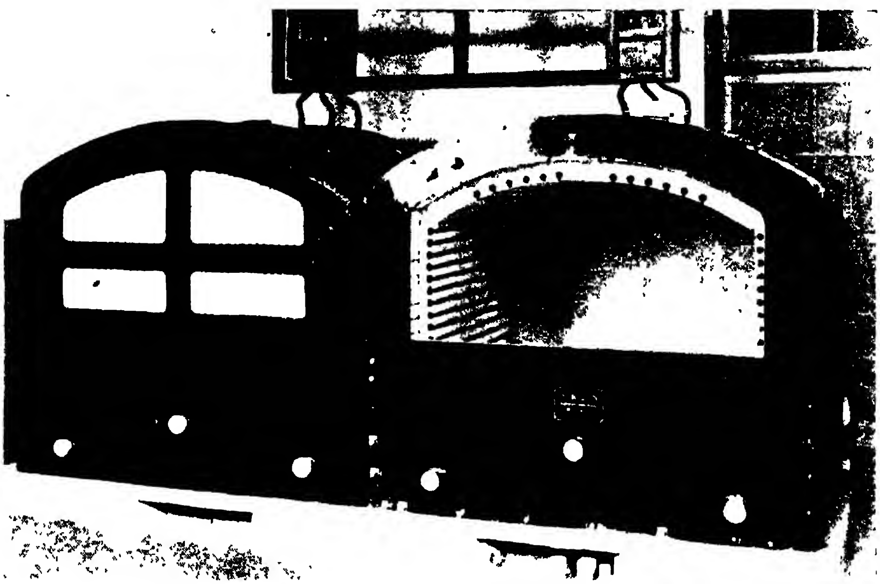


Fig. 1 Asahi-Denki Electric Kiln

DESCRIPTION OF TYPES IN USE.

The Naigai Electric Heating Appliance Manufacturing Co. and the Asahi Electric Co manufacture principally the square type of kiln, while the Chubu Co. makes a round type. The sizes listed are 8, 15, 45, 50, and 60 kW. The rectangular kiln rated at 35 kW., 200 V., manufactured by the Naigai Co., measures 82 cm. in height, 76 cm. in width, and 90 cm. in length, the volume being ·5 cubic metre. A new model has a capacity of 45 kW. and a volume of ·7 cubic metre.

The Chubu Co. make a 50 kW., 200 V., three-phase kiln, cylindrical in shape and opening from the top; the height and diameter are each 100 cm. and the volume is ·78 cubic metres. A small sample-making model of similar design is rated at 8 kW., and has a volume of ·06 cubic metre. The same makers supply a cylindrical 50 kW.

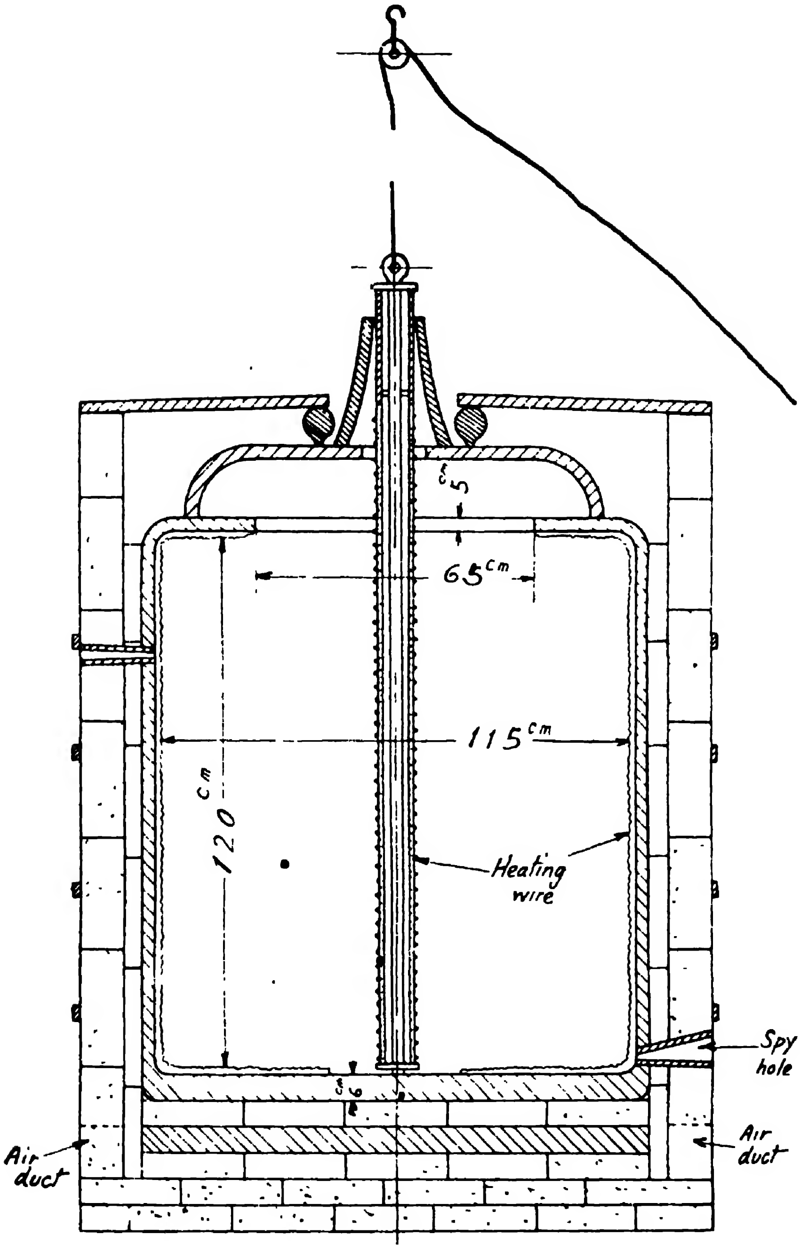

5 cm
65 cm
115 cm
120 cm
Heating wire
Spy hole
6 cm
Air duct
Air duct

Fig 2.

kiln with a single door in front for loading; a section of this is shown in Fig. 2. Fig 3 shows a similar kiln with two doors and a central heating element of 5 kW. to keep the temperature more uniform in the inside of the charge.

The temperature curve for the type of kiln shown in Fig. 2 is recorded in Fig. 4, showing that the duration of the power application is approximately five hours and the time required for the complete process, including the cooling, is about six hours.

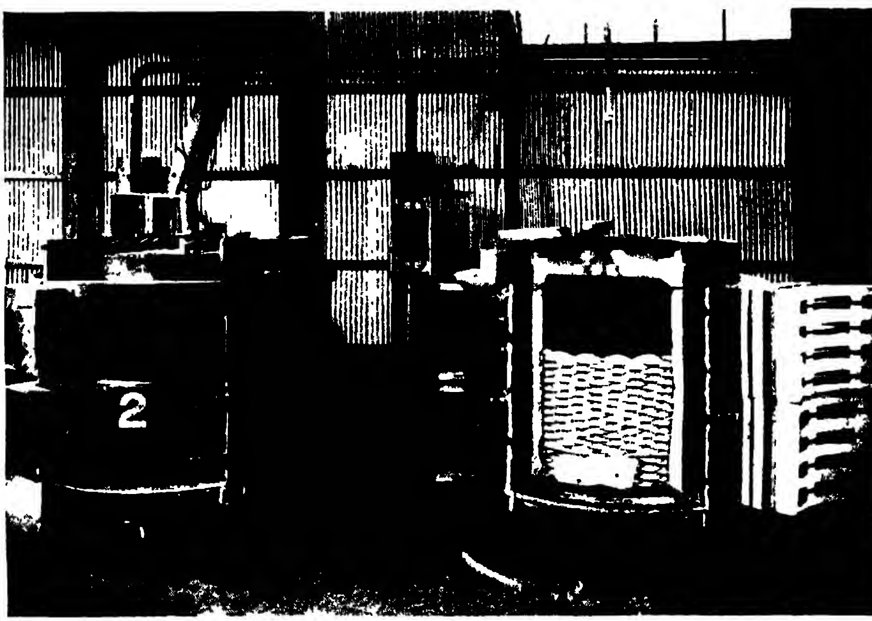
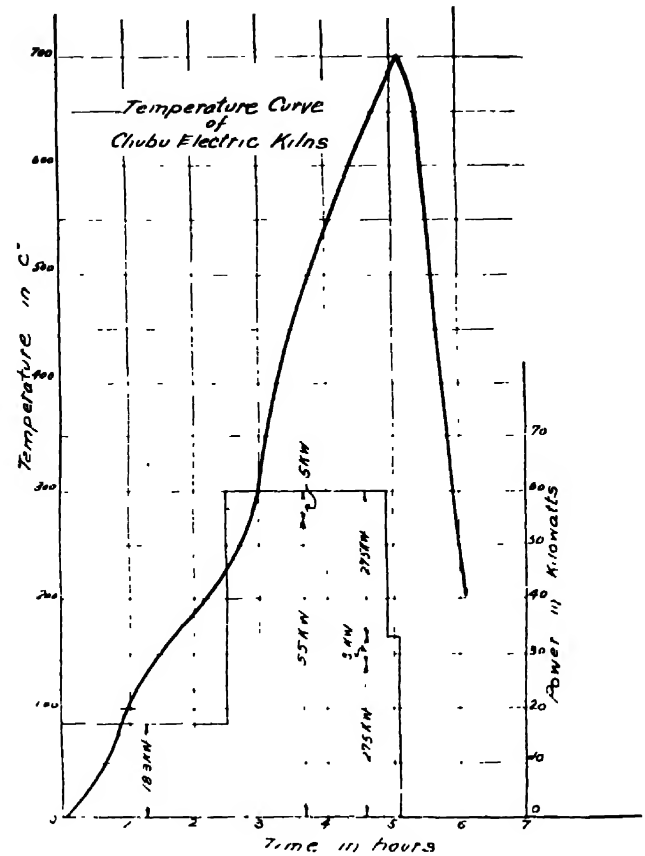


Fig. 3.
Chubu Electric Kiln. 3 Phase, 200 V. 50 kW.
(Centre rod is shown in kiln on left.)

It will be noticed that, in this test, the power applied is 18·3 kW. for the first two hours and a half, and 60 kW., of which 5 kW. is supplied by the centre element, during the next two hours and a half, after which it is brought down to 27·5 kW. by shutting off the power in the lower shelf. The temperature curve for a wood fire kiln is shown in Fig. 5 for comparison with that of Fig. 4. The heating time in this type of kiln is seven hours and a half, and the complete operation takes much longer.



The Asahi Electric Manufacturing Co. makes the type of electric kiln shown in Fig. 1 to take 45 kW. at 200 V. The volume is ·88 cubic metre (110 cm. by 97 cm. by 83 cm.). The Odake factory uses this type of kiln only, on account of its easy operation

THE FIRING PROCESS

Before describing the process of firing the colours electrically, the method used with a wood fire kiln will be outlined. Plain porcelain ware, which is treated first with a coat of glaze, is decorated with a pattern and then placed in a fire-proof pot, which is about 90 to 106 cm. in diameter and 106 to 120 cm in height. This pot is made to fit in a cylindrical kiln built of fire brick. If the ware is small enough, 800 to 1,000 articles can be packed in this pot. As a considerable time is necessary for one cycle of operations, makers usually start the firing process at noon and finish it by evening,

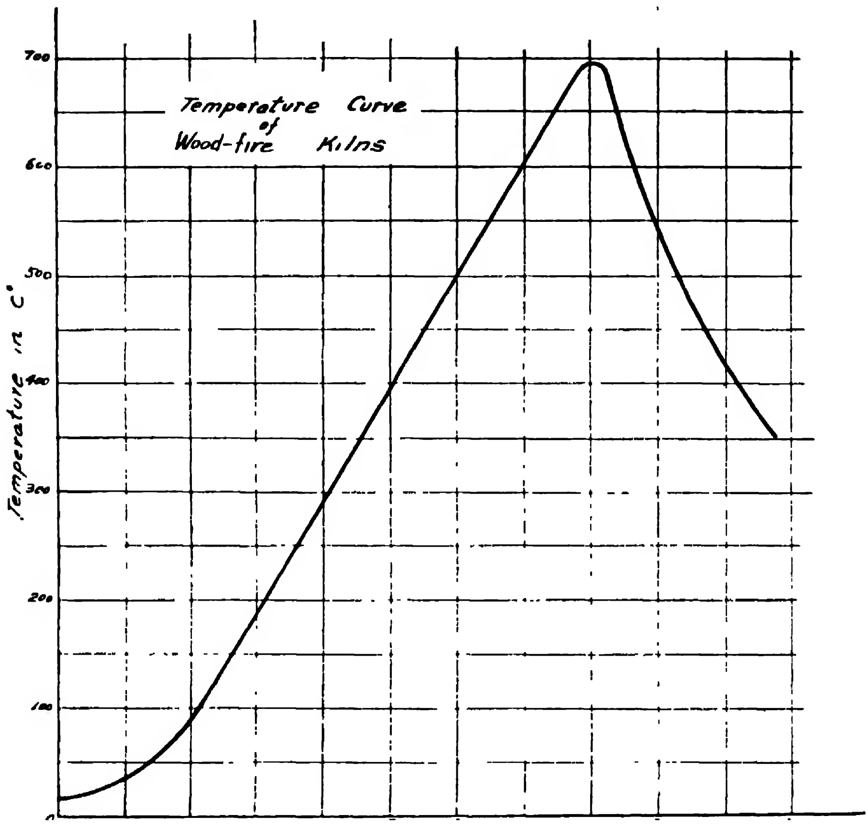


Fig. 5.

which gives them a chance to get the ware cooled by the next morning.

The temperature required to fuse the enamel is not the same in all cases, but varies with the different muffle colours. The temperature for producing gold lustre is usually about 500°C., but with a special kind it may sometimes be as high as 800°C. Some six to seven hours are required to complete the firing operation with a wood fire kiln. During the operation the stoker has occasionally to insert a test piece through a spy-hole in the kiln, this being the only means of judging the temperature inside the kiln known before the electric kiln came into use. The ware must not be taken out of the pot until it has cooled down sufficiently.

The process of firing the colour in an electric kiln is as follows. The plain porcelain ware, after being decorated, is thoroughly dried and arranged neatly on shelves inside the kiln. When the packing is completed, the cover is closed and the ventilating ducts

are opened at the top and bottom of the kiln. During the first three or four hours, only one-third of the heating power is applied to the kiln. During this "aburi," or "slow baking," the combustion of the glue and varnish contained in the enamel compounds takes place, and the organic gases so liberated are driven out of the kiln. Then, all ventilating ducts being closed, the full heating power is applied for two or three hours. As soon as the required temperature is reached, the heating current is shut off. The temperature is judged by the colour of the contents, which is seen through the spy-hole. Sometimes, instead of shutting off the current abruptly, the application of heat is continued at a reduced rate for about thirty minutes before being cut off completely. After the heating power is switched off, the kiln is allowed to stand for about two hours to cool off, before the ware is taken out. In the cooling an electric fan is often used to hasten the process. The size of ware fired may be as large as 48 cm. in diameter, as in the case of a plate, or 60 cm. in height, as in the case of a vase. At the other extreme, there may be a pepper-shaker 3 cm. in height, or even smaller. The total weight of the wares differs more or less according to the size and shape of the kiln, but 1,800 Kg., in the case of high class goods, and 2,600 Kg., in the case of cheap wares, can be put in at a time.

The temperature required varies with the colour chosen. 750°C. is required for cassius purple colour, while 500°C. may be sufficient for gold or coral lustre. The melting point of muffle colouring materials prepared at different places varies slightly, and the temperatures mentioned above are not to be taken as exact in all cases. The most important thing to be remembered throughout the process is that, as soon as the temperature is reached which makes the adhesion between the glazing material and the colouring matter complete, the application of heat should be discontinued immediately. This is really the secret of success or failure in the operation.

It is hardly possible to state precisely how many hours are required to complete the colouring process, as it largely depends on the thickness of the undecorated plain ware, the kind of potter's clay, and the variety of muffle colouring. The process of slow baking also ranges from two to four hours, varying according to the weight and arrangement of the wares, which cannot be uniform in all cases.

Then, as already described, two to three hours' full heat application follows, until the required temperature is reached. At this instant, the proper colour and glaze of the ware become clearly visible. Generally speaking, it may be taken that six hours for ordinary

kinds of ware and seven hours for those of good quality are required. Supposing the process starts at 11 p.m. (in order to take advantage of the cheap rate of midnight "off-peak" electric power) it will be finished about 6 o'clock the next morning. The potters naturally try to pack the kiln with as many articles as possible in order to increase their output, which also results in prolonging the time of operation.

The number of operators required varies with the different types of kiln, but it may be mentioned that five kilns of the round type with top opening take two men per day, while three square ones, or round ones with front opening, require only one man per day. It takes usually one hour to pack a kiln with wares.

The power consumption for the muffle colour process cannot be given definitely, as it varies with the shape and quality of wares, as well as with the variety of colour However, a 50 kW. kiln usually takes 200 to 250 kWh for one complete operation

SOME SPECIAL FEATURES OF THE ELECTRIC KILN

(*a*) *Superior Quality of Ware Produced.* In using wood, coal or water-gas, the formation of a certain amount of water vapour inside the furnace cannot be avoided. The temperature fluctuation due to the presence of water seems to be the principal cause of failure in maintaining the desired degree of temperature, upon which a good surface and colour are entirely dependent In the case of an electric kiln, not only is the water vapour absent, but the inside of the kiln is absolutely free from smoke or dust, both of which spoil the colouring.

(*b*) *Facility of Temperature Control* The wood fire kiln requires the constant attention of one skilled watchman, whose sole duty is to watch the degree of temperature through a spy hole Even with this personal attention the temperature control cannot be made very reliable, and wares consequently often show flaws By using electric kilns, the control of the temperature is a simple matter, and there is no possibility of making a mistake

(*c*) *Saving of Floor Space and Labour.* In porcelain factories using pine wood as fuel extra floor space has to be provided for storage, and hands have to be hired for chopping the wood to a proper size, for transferring it to a furnace room, then for stoking and so forth With an electric kiln such labour is eliminated

(*d*) *Cleanliness of Factory.* In the case of wood fire kilns the stokers' room has to be isolated because of dust and smoke, but with

an electric kiln this is unnecessary. Even a muffle colouring room can be built adjacent to an electric kiln.

(*e*) ***Prevention of Air Pollution and Fire Risks.*** The smoke from a stack is detrimental to public health and is often a cause of fire. Here, again, the superiority of an electric kiln is evident.

(*f*) *Saving of Fuel Costs.* The following estimate of cost is worked out for a kiln of 120 cm. diameter, this being the size most commonly used. 333 Kg. of pine wood will keep a kiln in operation for six or seven hours The price of pine wood being approximately 3 *sen*, or ¾d., per Kg. one operation will cost about 10 *yen* (£1). The fuel consumption varies according to the thickness and number of articles packed in a kiln, but this is a fair average figure A Chubu 60 kW. electric kiln with a capacity about equal to that of this 120 cm. diameter wood-fired kiln was found by the Nagoya P M Co., during a fifteen-day test, to consume on the average 230 kWh. per operation At ·0165 *yen* per kWh., which is the "midnight" power rate, the cost of one operation is 3·795 *yen*, a saving of 6·67 *yen*, or sixty-seven per cent of the fuel cost

(*g*) *Capital Cost and Life* The capital cost of wood-fired kiln, with a guaranteed life of 300 operations before needing repair, is estimated at 130 *yen* The electric kiln costs 540 *yen*, but this difference is balanced by the saving in operating expenses in the first three months The life of an electric kiln cannot yet be given with any certainty owing to the short time this type has been in use. However, the Naigai Electric Co.'s 40 kW kiln during 650 operations at the Odake Factory has only needed attention to twelve out of thirty-eight Nichrome II resistance wires, eight of these could be repaired, while four required complete replacement The 50 kW. Chubu kilns installed in the Hotta Factory are equipped with Chromel A heating wires, which show no signs of wear after 640 operations. These facts go to show that probably more wear and tear takes place in the refractory container which constitutes the kiln, than in the heating elements It should be possible, by a more substantial construction and a better method of attaching the resistance elements, to produce a kiln with a useful life of at least 900 operations.

(*h*) *Total Production Cost* Table I., prepared from the data for one year furnished by a number of porcelain manufacturers, gives a comparison of the total costs for an electric and a wood-fired kiln for one complete firing operation.

TABLE I.

	Expense items.			Cost per operation.
Electric kiln.		(300 operations per year.)		*Yen.*
	Electric power...	230 kWh. per operation at ·0165 *yen* per kWh.		3·795
	Labour	One man in charge of 6 kilns		·350
	Repairs... ...	Replacement of wire, etc., 90·00 per year		·300
	Interest and depreciation on kiln	Cost of kiln 540·00 *yen*.		
		Annual interest at 9·5%	51·30 *yen*.	
		Depreciation (life: one year)	540·00 ,,	
		Total annual charge per kiln	591·30 ,,	1·971
	Interest and depreciation on land and building (switching room)	Land, 3·3 sq. metres per kiln		
		Cost: at 30·00 *yen* per sq. metre	99·00 ,,	
		Annual interest at 9·5%	9·405 ,,	
		Building, 3·3 sq. metres floor space per kiln		
		Cost at 7·60 *yen* per sq. metre.	25·08 ,,	
		Annual interest at 9·5%	2·383 ,,	
		Depreciation (life: ten years)	2·508 ,,	
		Total annual charge per kiln	14·296 ,,	·048
		Total cost per operation ..		6·464 *yen*
Wood-fired kiln.		(288 operations per year)		*Yen.*
	Fuel (pine wood)	333 Kg. per operation at ·03 *yen* per Kg.		9·990
	Labour	Stoker and firewood chopper, etc. ...		2·000
	Interest charge on fuel in reserve store ...	Cost of firewood in reserve store	500·00 *yen*.	
		Annual interest at 9·5%	47·50 ,,	·162
	Interest and depreciation charge on kiln	Cost of kiln ...	180·00 ,,	
		Depreciation (life: one year)	180·00 ,,	
		Annual interest at 9·5%	17·10 ,,	
		Total annual charge per kiln	197·10 ,,	·685
	Interest and depreciation charge on land and building (fuel storage)	Land, 23·14 sq. metres per kiln		
		Cost: at 30·00 *yen* per sq. metre	694·20 ,,	
		Annual interest at 9·5%	65·949 ,,	
		Building, 23·14 sq. metres floor space per kiln.		
		Cost at 4·50 *yen* per sq. metre	104·13 ,,	
		Annual interest at 9·5%	9·893 ,,	
		Depreciation (life: ten years)	10·413 ,,	
		Total annual charge per kiln	86·255 ,,	·300
		Total cost per operation		13·137 *yen*

Conclusion

The increase in the number of electric kilns can be seen from the increase in both power demand and energy consumption in the Nagoya and Seto manufacturing districts. Before August 1924 the use of this type of kiln was only in the experimental stage. It is rather remarkable that such an increase in demand as has never before been experienced in any other industry has materialised within only about a couple of years. Table II. shows the growth very clearly. The effect of this on the daily load curve is clearly shown in Fig. 6, where the curve "A" represents the load throughout 24 hours recorded at the Yamaguchi-cho sub-station in Nagoya city, which began operation in December 1925. The curve "B" shows the load for the same district in January 1923. At that time the Yamaguchi-cho sub-station was not in existence, but the Minami-Buhei-cho sub-station was supplying energy to the same region.

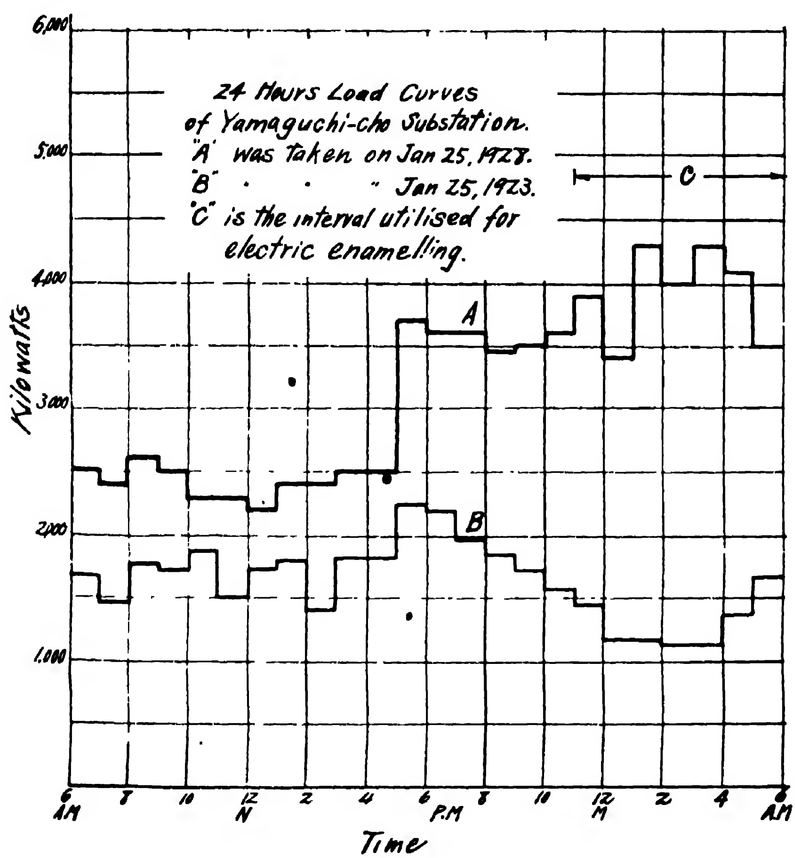


Fig. 6.

From the records of the load taken at the Minami-Buhei-cho sub-station, the curve "B" has been drawn, and the two curves are compared upon an equal basis. The interesting point of these two curves is that in "A" the big valley, which existed during the mid-night interval in "B" before electric kilns were adopted in these districts, is filled up. Thus it is obvious that this industrial power load is very desirable from the central station standpoint, all the more so because apparatus of the heat producing resistance type has an inherently high power factor. It is also shown in curve "A" that the station load factor has been greatly improved as a result of the employment of electric kilns during the off-peak period between 11 p.m. and 6 a.m.

In December 1927, the total power demand amounted to 9,713 kW. when 211 electric kilns were in operation. But in Nagoya city alone, there are now 120 factories, and 600 kilns in use. If the kilns of Seto district are added the total number will be over 800. If all of them were electrified the total power demand would amount to 40,000 kW. In consequence of the enactment of a measure prohibiting the night labour of factory girls in the cotton spinning industry, a considerable amount of midnight electric power will be released. This, again, ought to stimulate the use of electric power in the porcelain industry.

TABLE II.

	kW demand	kWh consumption	No. of consumers	No. kilns
Dec. 1924	40	4,160	1	1
Dec. 1925	840	74,481	12	19
Dec. 1926	4,335	171,139	13	89
Dec. 1927	9,713	1,002,669	52	211

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JAPAN: FIRING ENAMELS ON PORCELAIN

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ZUSAMMENFASSUNG

Der Wert der Gesamtproduktion japanischen Porzellanes für das Jahr 1926 betrug ca 61 000 000 *yen* (ca. £6,100,000) Das Zentrum der japanischen Porzellanindustrie liegt in der Provinz Aichi, deren Hauptstadt Nagoya ist. Von Alters her wurde als Brennstoff zum Brennen des Porzellanes Kiefernholz verwendet, ein Material, das zwar immer noch verhältnismässig billig ist, aber natürlich mit der allgemeinen Steigerung der Lebenskosten ebenfalls ziemlich im Wert gestiegen ist

Mit den grossen Fortschritten, die die japanische Elektrizitätsindustrie in den letzten Jahren gemacht hat lag es nahe diese Naturkraft auch in der Prozellanindustrie als Heizkraft heranzuziehen Vor einigen Jahren unternahm denn das Zweiggeschaft Nagoya der Toho-Elektrizitatswerke (Toho Denryoku), mit der Unterstützung mehrerer grosser Porzellan-Fabrikanten die Frage der Elektrifikation des Porzellan Brennens zu lösen Durch Einsetzen aller Kräfte gelang es endlich, nach Lösen der vielen Probleme erfolgreich ans Ziel zu gelangen Am Ende des Jahres 1927 betrug der Gesamtanschlusswert für Elektroofen im Versorg gsgebiete des Zweiggeschaftes Nagoya 9 713 kW, verteilt auf rund 211 Öfe Da zu diesem Zwecke fast ausschliesslich Nachtstrom verwendet wird, konnte der Strompreis auf den niedrigen Ansatz von 1,65 *sen* per kWh gebracht werden, einem monatlichen Mindestbezug von 4 ·36 kWh pro Ofen von 50 kW

Das bis Verfahren de Porz an-Brennens wa idrische feuerfesten ca 1 m Durch ser und 1,2 m Höhe werden die bemalten Porzellangesc irre sorgfältig eing gt resp aufgeschich tet Nach dem Zudecken wird die Tiegel in einen eben erd gestellt und mit Kiefernholz geheizt

verschiedene Typen von Elektroofen sind entwickelt worden und werde nun im Nagoya Gebiet allgemein g it Der erste Typ ist viereckig idere zylindrisch letzterer ist de der zur Zeit am meisten Anwendun funden hat Diese Öfe Drehstrom i 200 Vo und habe einen Anschlusswert von 50 kW Die Herstellungskoste Ofen betragen heute ca 500 *yen* und nem Durchme von 1 m und einer H Rauminhalt von rund 0 78 m³ Der Heizkörper ist auf der Innenseite und am Boden des H duet, das dazu verwendete Material ist Chrom

Die nun schon sehr ausgedehnte Anwendung dieser Elektroofen zeigt ihre Überlegenheit allem durch ihre gewaltigen Ersparnisse in den Brennstoffkosten Während der holzgefeuerte Ofen für eine Beschickung rund 10 *yen* für Feuerungsmaterial al erfordert, kostet der Strom für diese Arbeit im

Elektroofen nur 3,80 *yen*. Eine Beschickung des Elektroofens kostet also weniger als 40% des holzgefeuerten, was wohl ein enormer Fortschritt ist, von der viel regelmässigeren and besseren Qualität des fertigen Porzellanes noch ganz abgesehen.

Was die Lebensdauer der Chromel A Heizkorper anbetrifft, zeigt die Erfahrung, dass nach ca. 640 Beschickungen noch keine merklichen Veränderungen an diesen beobachtet werden konnen. Die allgemeine Praxis beweist, dass durchschnittlich 900 Beschickungen ohne grossere Reparaturen durchgefuhrt werden konnen.

INDUSTRIAL AND DOMESTIC USES OF COAL

OSAKA INDUSTRIAL ASSOCIATION

KENNOSUKE TSUJIMOTO

*Paper No. K*13

CONTENTS

I—Present Condition of the Fuel Supply of Japan

The presence in Japan of petroleum and coal has been known for 1,300 years, since 662-669 A.D., in the reign of Emperor Tenchi. It is, however, only within the past half century that they have been won in any large quantity.

Since the foundation of the Japanese Empire, 2,588 years ago, until the period of the Meiji Restoration, 1868, the same type of fuel was used in Japan, no marked improvement in the preparation of wood and charcoal having been made since the days of Emperor Nintoku, in 313-395 A.D.

For sixty years since the Meiji Restoration, Japan's industry has developed in an extraordinary manner with coal and petroleum

as the fuels used. Kindling wood and charcoal are, however, still the principal materials for fuel in Japan.

Japan's annual production of coal in recent years has been about 30,000,000 tons, of which a portion has been exported. On the other hand, some bituminous and anthracite coals have been imported. The annual consumption at home may be estimated at 28,150,000 tons. This total consumption may be roughly classified as follows :—

	Tons (1,000 Kg
Factories	14,000,000
Railways and ships	6,400,000
Mining and metallurgy	4,000,000
Pottery and salt concentration ...	1,400,000
Town's gas manufacture	1,260,000
Domestic, bituminous	700,000
Domestic, anthracite	150,000
Total	28,150,000

The annual petroleum production of Japan is about 250,000 tons, out of a total consumption of about 950,000 tons.

According to the record made by the Imperial Forestry Association of Japan, in 1919, Japan felled timber for fuel amounting to 2,986,680,000 cu ft., or 23,334,430 cords of 128 cu. ft., and 697,405,250 cu. ft., or 5,440,000 cords of wood were used for general purposes, including building, etc. In addition, the annual imports of wood in recent years amounted to 93,667,160 cu. ft. a year.

Japan has large resources of water power, and the annual amount of electricity produced by water power is 5,832,287,334 kWh. from equipment of 1,459,200 kW. capacity. Supposing that 1 kWh. of electricity is generated by an average of 2·24 lb. of coal, the electricity developed annually from water power in Japan is the equivalent of 9,798,000 tons of coal. In addition, Japan consumes annually about 60,000,000 tons of coal or its substitute as fuel for producing heat and power.

The various kinds of fuel used annually for heat and power production, their estimated equivalents in coal and their monetary values, are shown in the following table :—

	Aggregate amount	Quantity in terms of coal. Tons (1,000 Kg)	Monetary value in pounds sterling (£1 = 10 yen)
Coal, tons	28,150,000	28,150,000	42,225,000
Petroleum, tons	950,000	1,900,000	6,960,000
Kindling wood for domestic use, cu. ft. .	1,518,390,000	10,122,000	75,919,500
Raw wood for charcoal, cu ft	1,032,560,000	6,900,000	51,628,000
Raw wood for industrial charcoal, cu ft	435,730,000	2,900,000	21,786,000
Water power, kWh	[illegible],832,287,334	[illegible],798,000	29,161,436
Agricultural and domestic wastes, tons . . .	1,000,000	1,000,000	1 500,000
Total .		60,770,000	229,178,936

The total amount in terms of coal is 60,770,000 tons and in monetary value is about £230,000,000, based upon the following average prices :--

Coal per ton, 30 shillings.
Petroleum per ton 144 shillings
Fuel wood per cord (128 cu ft) 128 shillings
Water power per kWh 1¼ pence

Out of the total cost of fuel of £230,000,000, about £133,601,500 is for domestic fuel The amount for domestic fuel is, therefore, larger than that for industrial fuel. This is due to the special conditions in Japan, where wood and charcoal are used extensively as domestic fuel.

The consumption of new coal in Japan is increasing, and the home supplies, which are not large, can be supplemented by imports from China, where large supplies are available.

II—Japan's White Coal: Water Power

As stated, fuel equivalent to 30,000,000 tons of coal has been obtained in Japan by means of hydro-electric power, wood, and charcoal. According to the surveys made by the Department of Communications, the total water power available in the drought season is about 6,400,000 H.P., and the amount on the basis of an average season that can be utilised during six months of a year is about 14,000,000 H.P. The water power capacity completed

at the end of 1924 was about 1,500,000 kilowatts, of which 45 per cent. was actually utilised, producing 5,832,287,334 kWh. during the year. When the hydro-electric stations for the drought season, capable of producing 6,400,000 H.P., are completed, and 50 per cent. of the capacity is available for actual use, the total hydro-electric power capacity throughout the year will become about 21,000,000,000 kWh.

Assuming that 2·24 lb. of coal is needed to produce one kWh. of electricity, Japan's water power in the drought season will be equivalent to the consumption of 21,000,000 tons of coal in a year. Calculating the average-season water power for six months in a year and the drought-season water power for the remaining six months, and estimating 50 per cent. of these possibilities for actual use, the power available will become as follows :—

Average-season power	43,800,000,000 kWh.
Drought-season power	10,500,000,000 kWh.

This total will be equivalent to 54,300,000 tons of coal as fuel In 1925, however, the hydro-electric power produced was equivalent to only 9,798,000 tons of coal. About five times as much hydro-electric power capacity still remains to be used as a substitute for coal.

III—Wood and Charcoal as Fuel

In 1919, the timber felled in Japan was as follows :—

For industrial use	697,400,000 cu. ft. equals	5,440,000 cords.
For fuel ..	2,986,680,000 cu. ft. equals	23,333,430 cords.

The calorific value of the wood used as fuel is theoretically equivalent to about 20,000,000 tons of coal, but the practical value is equivalent to only 12,000,000 tons of coal. During the period of national seclusion before the Meiji Era, Japan was self-supporting in the supply of wood, but consumption has since increased.

Japan's forests can yield 11,700,000 cords of 128 cu. ft. annually with 15 years allowed as an average period for growth. As the annual amount of timber felled is about 24,000,000 cords, the virgin forests are being cut down. At the present rate, Japan's mountains will become barren of trees in 30 years. It is absolutely necessary that Japan should resolutely limit the use of wood to 8,500,000 cords as fuel. Otherwise, Japan will not only suffer seriously from floods, consequent devastation of arable land, and loss of animals and of human lives, but will also entirely lose the source of hydro-electric power.

Japan now faces the urgent problem of breaking away from long-established practices as regards fuel. She should limit the cutting down of trees to 14,000,000 cords, that is 180,000,000 cu. ft. for wood and charcoal, and fill the gap by means of materials other than wood. If a proper material is found as a substitute for 14,000,000 cords of wood as domestic fuel, the problem will be solved.

IV—Domestic Fuel with Coal as Raw Material

The Japanese house is different in construction from the European or American, and the heating system is likewise different, owing to the long-established practice of using wood and charcoal as fuel. Ninety per cent. of the Japanese houses have *shoji* (paper partition), *tatami* (straw mat) in their rooms, where *hibachi* (portable charcoal stove) and *konro* (portable cooking stove) are installed to burn charcoal. For the *hettsui* (cooking stove for rice) and bath tubs, kindling wood is used.

For warming the rooms, there is *irori* (open hearth) cut in below the level of the matted floor to burn wood or charcoal, mostly to be found in cold northern districts. There is also *kotatsu* (another kind of portable stove) in which charcoal or *tadon* (ball-shaped mass of charcoal breeze) is burned. In warmer districts, *hibachi* and *anka* (another kind of portable stove) are mostly in use, in which are burnt charcoal or *tadon*.

Irori is translated "open hearth" for convenience, but the *irori* is not like the open hearth in England, in which coal is burned vertically to produce horizontal radiant heat. A plain horizontal hearth is cut as *irori* in the centre or a corner of a room, three feet square or thereabouts, with the bed of the hearth cemented with clay. Upon the ash of wood and with no grate, kindling wood is burned horizontally. The flames and the hot combustion products diffuse in the room in all directions. Thus radiant heat as well as convective heat can be secured in rather an ideal manner. If properly burned, soot and smoke can be prevented from scattering about, so that no chimney is needed. Instead of a chimney, however, an opening is provided in the ceiling for ventilation to the roof.

In cities, too, the majority of houses are Japanese in style. Only a very few houses use coal or coke for heating bath tubs or stoves, and a very few more use coal for heating water other than for baths. In the majority of households wood and charcoal are used as fuel. Consequently, only 700,000 tons of raw coal are used annually for domestic purposes.

In about 100 cities and towns coal gas is supplied as town's gas.

This gas is produced mostly in horizontal retorts. The calorific value is between 400 and 480 B.Th.U. per cu. ft. The Tully, Rambush, Strache, and Bamag methods are used for total gasification. The waterless gasholder is also installed and, indeed, an up-to-date town's gas system is employed. Nevertheless, the total amount of raw coal used annually for the production of gas is only about 1,260,000 tons

Gas is a convenient fuel, but due to the lack of the necessary equipment in the Japanese house, gas coke is unsuitable for use as domestic fuel. Moreover, as the hard coke from beehive or by-product ovens meets the industrial need, the demand for gas coke is limited. While gas as fuel is welcomed, coke is not. Consequently, there is little prospect of the further development of the carbonisation of coal for the production of town's gas.

As charcoal substitutes, the following are generally recognised :—

1. Anthracite.
2. Beehive-shaped anthracite briquettes.
3. Pea shaped anthracite briquettes
4. Gas coke
5. Semi-coke from bituminous coal, made by the following means :
   (a) Kopper's modified oven (Fushun Colliery).
   (b) Externally heated vertical retort (Kaijima Carbonisation Company)
   (c) Internally heated furnace (Hôkoku Colliery)
   (d) Gara semi-coke, by heap carbonisation without retort or furnace
   (e) Seitan semi-coke, made in horizontal retort externally heated (Ube Carbonisation Company)
   (f) X tan semi-coke made in horizontal rotary retort externally heated (Osaka Gas Company).

6. "Ligno-Briquettes," smokeless fuel made by low-temperature carbonisation of pitch-bound bituminous coal and desulphurised.

Dr. Yoshikiyo Oshima, Chief of the Fuel Research Station of the Department of Commerce and Industry, says (J. Soc. Japan, 1927, 63, 110) : "Owing to its rapidly increasing price and the low efficiency of its domestic use, charcoal is being replaced by many kinds of substitutes, mostly briquettes, although charcoal is still the most popular domestic fuel in Japan. Anthracite is chiefly used as raw material, and it forms 83 per cent of the total production

"The price of charcoal does not vary much throughout the country and it is not cheaper than Y100 (approximately £10) per ton.

while substitutes are mostly procurable at prices ranging from Y50 to Y70 per ton."

Mr. Ryuji Kata, fuel expert, says. (J. Fuel Soc., Japan, 1927, 59, 64) : "Most Japanese houses use charcoal in a furnace with or without grate, under a very slow draught, and as these furnaces have no chimney, the ignition temperature and the burning rate are both equally important factors in the specification of charcoal, as well as the briquette fuel to be substituted for it. Owing to the increasingly high price of charcoal during the last ten years, many proposals and plans were made to manufacture proper substitutes, but none of them has yet been satisfactorily used."

V—Ligno-Briquettes, a New Charcoal Substitute

Natural smokeless coal, or the same coal subject to slight treatment, is not suitable for use in Japanese houses as domestic fuel, because of the construction of the houses, if it remains merely smokeless. Coal produced in Japan is almost entirely bituminous; that is, smoky, and the greater part of it lacks coking power. Slack coal may be dressed by proper preparations, the ash removed, and the heat value increased, thereby making the quality of the coal uniform, but slack is slack after all. If slack can be made into lump coal, it would help much in readjusting the supply and demand for coal. Until now, no adequate method of utilising slack coal for domestic fuel has been found.

In the manufacture of "ligno-briquettes," various bituminous coals which are readily found in this country are used. By pretreatment, their coking or swelling properties are properly adjusted, and they are then blended. The method of using flux for sulphur fixation is applied. The briquettes made with bitumen binder are then subjected to low-temperature carbonisation by carefully regulated external heating The ligno-briquettes thus produced are most suitable for domestic use as well as for such an industry peculiar to Japan as sericulture.

For sericulture, the ligno-briquettes are used as fuel for the following purposes: —

1 For preserving temperature in the nursery throughout the five sleeps after the eggs are hatched until the worms are fully grown.

2. During the period of making cocoons.

3. For drying cocoons.

4. For the work of reeling.

Charcoal has hitherto been employed for these services. As the price of charcoal has risen, the sericulturists have searched for

charcoal substitutes which will really serve the purpose, as the so-called substitutes have not proved satisfactory. Semi-coke, lignite-char, or *Grudekoks* from Germany cannot satisfy the Japanese needs. The Japanese people will not hesitate to use any solid fuel if it is made of coal properly treated and meeting the following conditions:—

(a) Applicable to heating arrangements already in use.
(b) Suitable for water quenching and dry quenching to make it serviceable on a subsequent occasion.
(c) Smokeless and odourless.
(d) Cheap and easy to obtain.

Many kinds of smokeless fuel made in the past did not meet these requirements. There are 200 kinds of proved processes in the world for producing low-temperature coke. In Japan, there are six plants where low-temperature carbonisation is applied commercially. Of the six, five use a specific coal, while four apply external heating and one internal heating. The coking, swelling, and sulphur qualities are prescribed by the natural qualities of the coal used. Consequently, only in rare cases will a fuel be produced making an appeal to the majority of consumers.

If the substitutes are made by using blended slack coal, the choice of the coal can be made quite freely. In manufacturing ligno-briquettes, this method was adopted. Other features of the process are described under separate headings.

(a) Why the briquette shape was adopted.—For use in the Japanese house, with its existing heating facilities, charcoal pieces of cylindrical form with a diameter of one to two inches and a length of three inches are most suitable. The substitute fuel must be made of that shape and to those dimensions. The ligno-briquette resembles charcoal in many respects. For instance, in using it in a *konro* (portable cooking stove), it is rather superior to charcoal.

In making ligno-briquettes, bituminous coal is used as the principal raw material, to which flux for fixation of the sulphur and bitumen binder (for convenience, pitch) are added, and then pressed. The raw briquettes thus made are charged into a vertical retort and are heated externally for rapid carbonisation, while sulphur fixation is carried out at the same time. The briquettes go through the process in one stage, each piece retaining its individuality. After they are taken out of the retort, partial desulphurisation is effected by water quenching.

There are three stages in the process of manufacture of the ligno-briquettes :—

1. Pre-treatment of coals.

2. Quick carbonisation of pitch-bound briquettes at low temperature by external heating.

3. Desulphurisation and fixation of sulphur in the ash.

(*b*) *Pre-treatment of coals.*—The manufacture of ligno-briquettes is an intermittent process for securing smokeless briquettes retaining their individual form. As the raw briquettes are charged into a vertical retort and are heated, it is necessary to ensure that the coal particles do not swell or fall into a too plastic state. To neutralise the coking quality and avoid swelling and sticking, the coal is subjected to a preliminary treatment.

For this purpose, slack coal is charged into a revolving cylinder

Fig. 1. Revolving Cylinder for the Pre-treatment of Coal

and the hot flue gases from a coal fire are introduced into it and come into direct contact with the charge. The cylinder is shown in Fig. 1. With non-coking coal, the process is limited to drying only, but with coking coal thermal control is exercised so that the binding constituent, the gamma-compound, is oxidised, and so that the coking property is reduced to a certain extent.

As the constituents of the mineral matter contained in coal have important relations to the combustibility and sulphur-fixation property of the resulting ligno-briquettes, the nature of the coal and its constituents are carefully examined beforehand. In many instances lime constituent is lacking. Slaked lime is then added as

an auxiliary. In this way slack coals are blended to be made into raw material for briquettes.

(c) *Briquetting of blended coals with bitumen binder under pressure.* —In the process of carbonisation it is important to make the heat transmission rapid, not only to increase the throughput of the retort for economic reasons, but also to ensure rapid heat penetration, as otherwise good individual briquettes cannot be produced. For this purpose, the charges are introduced into the retort in briquette form, bitumen binder (pitch) being added. In the ligno-briquette process, the binding property of raw coal is reduced and in its stead pitch as binder is added. This serves as a means of control.

The pitch used as binder is between 10 to 12 per cent of the total. A pressure of 1,500 lb. per square inch is applied to it. The briquettes made are $1\frac{1}{2}$ oz. each in weight.

Fig. 2 shows the briquettes formed into shape by the roll briquetting machine being hardened by air cooling whilst conveyed by the belt conveyor.

As the hot briquettes are carried by the belt conveyor into the open air outside the building to an open-air heap for storage, they emit steam and the briquettes are cooled and thus solidified

(d) *Difficulties encountered in the carbonisation of pitch-bound briquettes.* - As pitch is brittle, so is pitch-bound briquette. Pitch is softened and melted at 60°C. to 90°C. If subjected to a higher temperature, it loses volatile matter. Again, at 360°C it solidifies and forms pitch-coke of spongy structure.

These changes also take place in pitch-bound slack coal briquettes. It has hitherto been regarded by the recognised authorities as impossible to manufacture individual carbonised briquettes out of pitch-bound briquettes by external heating in a low-temperature carbonisation process.

Lander and McKay (Low Temperature Carbonisation, London, 1924, 216) state: " In order to get a satisfactory solid product in a marketable condition, lump material was essential. This has been attained by simple briquetting before carbonisation. Ordinary briquetting with normal pressure, and entirely normal disintegration of the slack, was considered essential from a commercial point of view for many reasons, but it was obvious that, with a binder of the nature of pitch introduced into the fuel, it would be impossible to carry out satisfactorily any method of carbonisation by external heat application, owing to the tendency which the binder would have to flow out of the material at a temperature lower than that of the incipient fusion of the substitutes "

Curtis, Daughton and Chapman (Chem. and Met. Eng., 1923, Jan.) state: "The worst trouble of the secondary retorts (of the Carbo-coal process), however, was that the briquettes would hang up in the chambers, and it required much poking with long rods to get them out. So, under the normal conditions of the operation, they were outside the limit of the workable equipment."

McIntire (Ind. and Eng. Chem., Jan., 1927, 14) states: "Also, as the heat gradually penetrated the charge (pitch-bound semi-coke briquettes charged into the Carbo-coal secondary oven), the inner briquettes became at first soft and pliable. The weight of the briquettes above forced and squeezed the mass of briquettes, together, so that within a couple of hours the charge has been

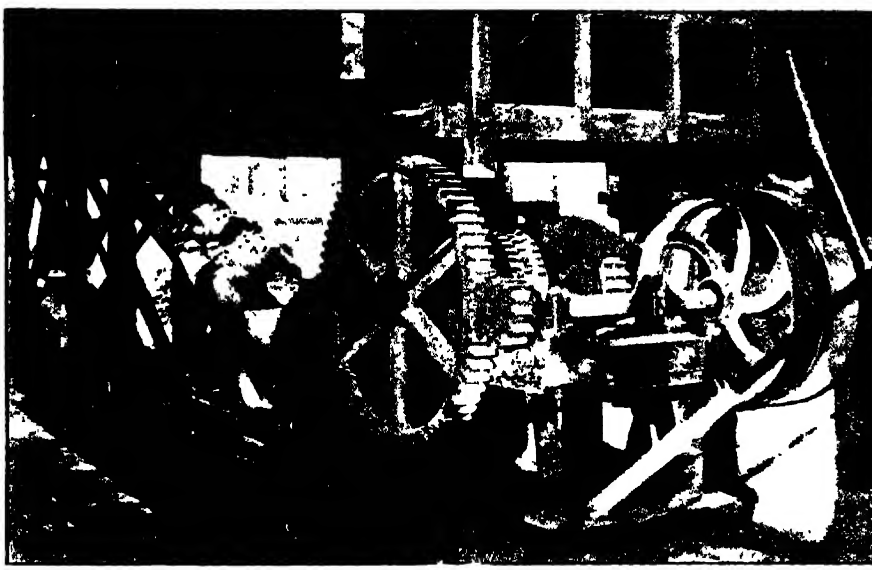

Fig. 2 Briquetting Press with Belt Conveyor

transformed from a batch of individual briquettes into a mass of formless sticky portions of broken and fused briquettes, quite difficult, if not impossible, to discharge from the oven. The problem, therefore, was to devise an apparatus that would carbonise these briquettes without, on the one hand, breakage due to heat shock; on the other, any tendency to fuse the soft briquettes by the dead weight of the other briquettes above them."

In Fig. 3 is shown the product obtained in an early stage of the development of the ligno-briquette process. The individual raw briquettes have been fused together by the liquated pitch. It was difficult to discharge this material from the retort. Moreover, in one

stage of operation, it was difficult to secure smokeless pieces with an individual form suitable for domestic fuel.

At a later stage, pitch-bound briquettes were charged into the retort with coke breeze in order to prevent them from cementing together. The coke breeze, however, was caught by the pitch at the surface of the briquettes, thus making a *kanoko-mochi*. This is shown in Fig. 4.

Should the pitch become plastic because of heat, there is a possibility of the briquettes at the bottom part being deformed. In order to prevent such deformation, the following methods were considered :—

(a) To prevent the briquettes from touching each other, they were placed in a single file on a travelling belt conveyor and carbonised in a tunnel kiln. Shelves were provided for in the retort. This

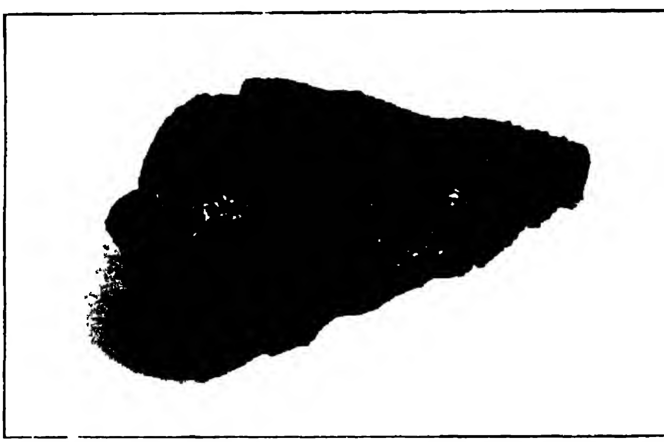

Fig. 3. Carbonised briquettes. Individual briquettes fused together by the liquated pitch

method was found defective in that the heat transmission was imperfect, and mechanical troubles arose, so that it was not fit for large-scale operation.

(b) Another method considered was that of internal heating. When the superheated gas passed through the interstices of the briquettes charged into the retort, the briquettes were heated and the pitch liquidated. The pitch was vapourised owing to the superheated gas. Similarly the gamma-compounds having binding property also vapourised and turned into gas. As these properties were neutralised by the action of the hot gas used as the heating medium, the briquettes charged into the furnace did not stick together into a lump. In this method, poking was resorted to in order to let the heating gas pass through the charged raw-briquette mass uniformly.

McIntire (International Conference on Bituminous Coal, 1926, 660) also says : "One way to prevent the mass from being squeezed together due to the pressure of the upper briquettes would be to carbonise them in very thin layers, so that no briquette would have to support more than the weight of one other briquette. In developing this idea, internally heated retorts, tunnel kilns, and batch retorts were all suggested and tried. One of the difficulties encountered in attempting to operate an internally heated retort was due to channeling. It was expected that the passage of hot inert gas around a batch of briquettes would carbonise each briquette uniformly without any shock or breakage. Actually, as the hot gases began to circulate, they did not flow evenly through the mass, but discovered special channels, probably due to the minute

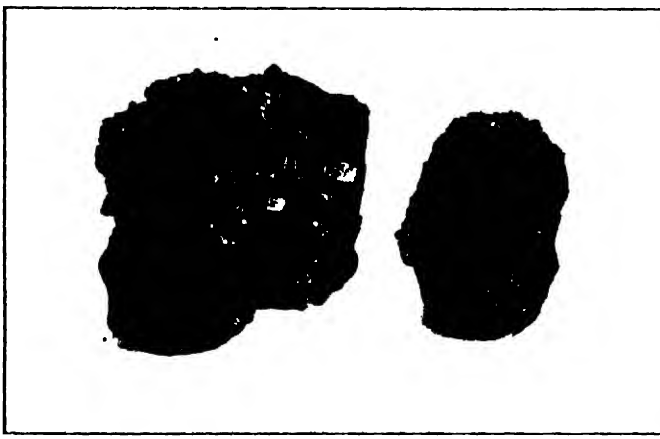

Fig. 4 *Kanoko-mochi*

difference of friction head, and once found nearly all the heating gases flowed through these special channels."

Consequently, carbonisation is imperfect with this method, and some of the briquettes will smoke. Unlike in a European or American house, in a Japanese house it is necessary that the fuel be absolutely smokeless.

(*e*) *Thermal control of pitch-bound briquette carbonisation.*—In the ligno-briquette process, the following principles are observed :—

1. During the carbonisation, the charge shall be stationary.
2. The retort shall have a high thermal conductivity.
3. Thermal control shall be perfect.

As a result of study concerning the material used for making the retort, its construction and shape, the patent Tozer Retort (Fig. 5) was selected. By the use of this retort, the following advantages

were gained as announced by Mr. Tozer: "When a caking bituminous coal is carbonised, the coke comes out in slabs practically the length or full height of the retort, and configuring exactly to the shape of the cells in the retort. If the coal is a non-caking one, the coke comes out almost in the same physical condition as the entering charge."

By using this retort, however, charging pitch-bound raw briquettes and taking care that the thermal control is properly done (as is actually done in Osaka), carbonised individual briquettes can be produced without being fused into a mass.

Carbonisation is performed as an intermittent process. If the coal to be carbonised is charged in an empty pre-heated retort, the

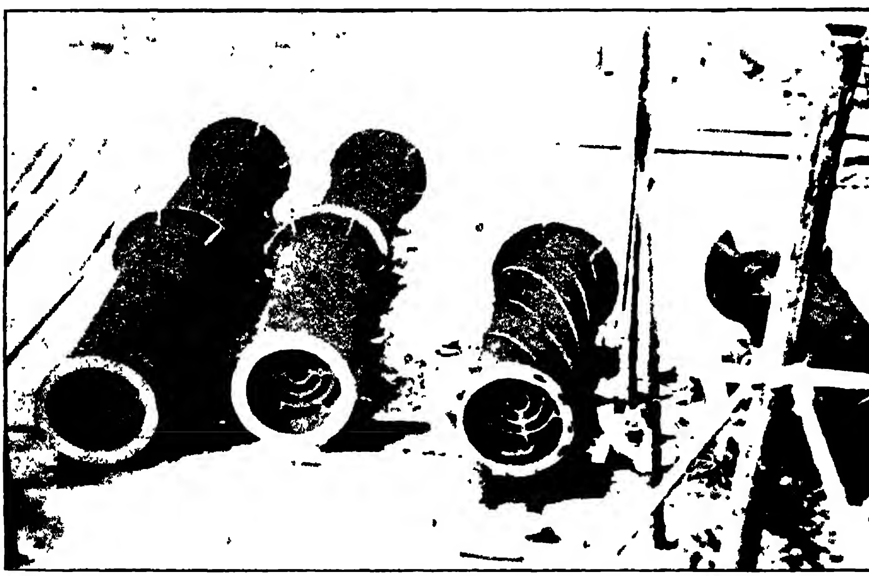

Fig. 5. Tozer retorts.

temperature of the retort will at once fall, due to the endothermic action in the earlier stage. The degree of the fall of the heat depends upon the quantity of the charge and the thermal capacity of the retort. If the quantity of the charge of raw briquettes is in excess of that for which the retort has been pre-heated, the fall of temperature will be so large that the constant supply of heat by external heating will not readily heat the raw briquettes inside the retort and the carbonisation will require a longer time than otherwise. In regular working, the carbonisation is completed in a little less than eight hours after the raw briquettes are charged. Meanwhile, 3,000 to 6,000 cu. ft. of low-temperature gas are evolved per ton charged. This gas is used to heat the retort.

Once the correct thermal state is lost, the amount of gas evolved will decrease, so that it will become necessary to use auxiliary fuel produced from a gas producer. In that event, a longer time will be needed for carbonisation, thereby reducing the throughput. The value of the products will also decrease. This indicates the importance of thermal control

The retort actually in use has an effective height of 10 ft.; the internal diameter at the top is 2 ft. 9 in., and at the bottom 3 ft. 8 in. The retort is divided into twelve annular spaces by three concentric annular wall rings and twelve radial ribs, and weighs 7 tons. When bituminous slack coal is charged into these twelve spaces, the retort contains about 1·3 tons of coal. The full charge of briquettes is just 1 ton of 1,000 Kg The briquettes should be sized to suit this condition, and weigh on an average $1\frac{1}{2}$ oz. The pitch serving as briquette binder will gradually soften and liquidate out and flow on the surface of each individual briquette Then the briquettes will cement together into a single mass having a conglomerate structure, as shown in Fig. 3. Such carbonised products have little value in Japan. The carbonising unit covering the entire furnace body, including the retorts, if it possesses large thermal capacity, will help to prevent the temperature of the briquettes, suddenly charged into the retorts, from falling below 400 C This is due to the fact that the construction of the retort is such that the outer wall, the concentrically lined annular inner walls, and the twelve ribs radially crossing, are all made of heavy metal castings. The charged briquettes mostly attach to the walls or the ribs Even those further away will stay within two inches of the heating surfaces (walls and ribs). Consequently, the heat transmission is very rapid The interstices between the briquettes charged into the annular spaces of the retort become gas passages. As the temperature of the external wall of the retort and of the inner walls and ribs is nearly equal, the portions of the briquettes coming into contact with the hot surface are at once heated by conduction. The gas evolved from the briquettes transmits its sensible heat into the inside of the porous briquettes and to their surfaces In this way, all of the briquettes are rapidly heated. Meanwhile the retort is heated externally and constantly transmits heat to the charged briquettes. The resultant effect is that the temperature of the emergent gas rapidly changes and a minimum temperature of 400 C. should be maintained by adjusting the quantity of briquettes charged

The carbonisation is conducted intermittently, and the carbonised briquettes are simultaneously discharged from the bottom of the

retort. The gas produced by the auxiliary gas producer, previously mentioned, is employed at the proper time, so that the empty retort is suddenly heated within the allowance of the structure, thereby giving sufficient thermal capacity. If one ton of raw briquettes is charged into a retort having seven tons dead weight, the individual carbonised briquettes are carbonised in an average of eight hours.

When the briquettes are carbonised in this manner by quick heating, the time in which the pitch softens and liquidates will be very short and it will instantaneously harden. The volatile matter

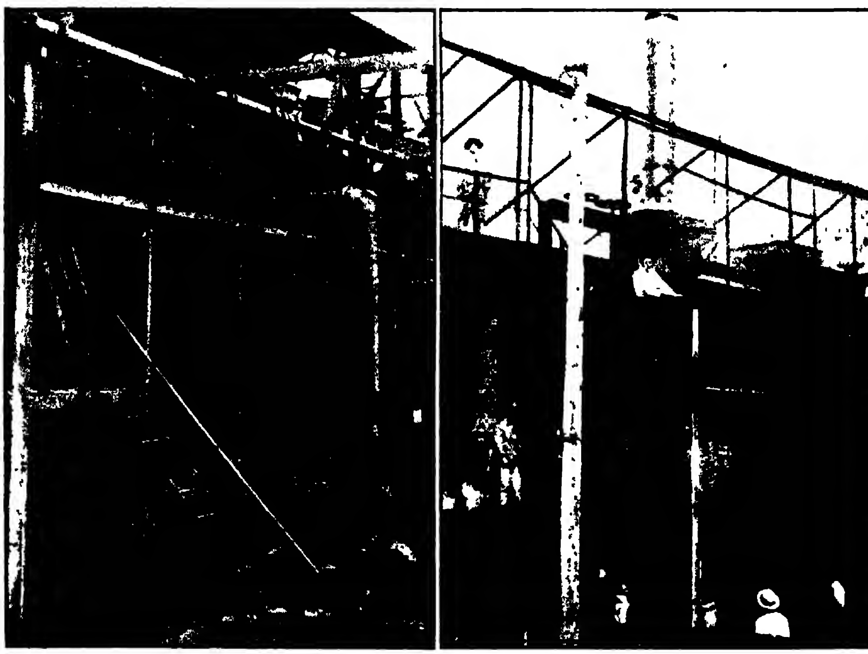

Fig. 6. Carbonisation furnaces.

in the pitch will then evaporate, and the gamma-compounds among the constituents of the pitch will suddenly decompose into gases and pitch coke. At that moment, the pitch coke cements the small coal particles and binds them together. The pitch shows its capacity as binder at the moment of carbonisation. When the briquettes are made, the pitch first reaches a molten state and becomes plastic and mixes with the coal particles to form the briquettes. The action of the pitch at that moment is that, while the briquettes are cooled after pressing, the pitch itself hardens and binds the coal particles, thus producing brittle briquettes. (*Vide* Fig. 2.) After

they are once carbonised the coal particles become smokeless, and the agglutination resulting when the gamma-compounds in the pitch are transformed into the pitch coke, makes the briquettes strong and smokeless, forming the so-called ligno-briquettes.

The ligno-briquette has a cellular structure throughout, however irregular, and it burns easily and freely like good coal. As the carbonised coal particles in the ligno-briquette are bound by the pitch coke, it is able to withstand the action of water. Moreover, once it ignites it retains its form intact until it is completely burned through.

Fig. 6 is a front view of the carbonisation furnaces showing the gas exhausting pipes and goose-neck connections, and Fig. 7 a view of the hydraulic mains and anti-dip valves of the carbonising unit

(*f*) *The desulphurisation of the briquettes and fixation of sulphur in the ash.*—The sulphurous fumes emitted from the open domestic fire are most detestable. As a result of careful study made of charcoal, it was learned that the total quantity of sulphur contained therein was as low as 0·008 to 0·1 per cent. The low sulphur content obviates the nuisance. Actually, however, the sulphurous odour from domestic fuel does not depend upon the total quantity of sulphur contained by the fuel, but upon the quantity of combustible sulphur. In other words, it depends upon the state of distribution of sulphur in the constituents which compose the fuel. Chemically speaking, the combustible sulphur is the sulphur emitted as sulphur dioxide by oxidation while the fuel is being burned. The sulphur which remains in the ash of the fuel may be called non-combustible sulphur. As domestic fuel for Japan, most of the fuel material must contain 0·1 per cent. or less of combustible sulphur.

Most of the so-called fuel substitutes prepared carelessly with raw coal as material have failed in that respect. The prepared pressed briquettes (whatever kind of binder is used) with anthracite as raw material, or the solid residue obtained on carbonising coal at a high or low temperature (coke or semi-coke), or any kind of briquette made from these carbonised residues are certainly all smokeless. They can be ignited easily and are free burning. The kinds of smokeless fuel which are not welcomed as domestic fuel in Japanese households are those containing a large quantity of combustible sulphur.

The ligno-briquette is an ideal domestic fuel when made of bituminous coal which has been specially treated to reduce the combustible sulphur content. Sulphur in some form is an indispensable constituent of bituminous coal (either in the form of sulphate, sulphide,

or organic sulphur compound). By carbonisation it is converted into one or other of two types of sulphur compound. These may be termed stable and unstable. The unstable sulphur becomes elementary sulphur or gaseous compounds and behaves as the volatile matter evolved from the raw material; the stable sulphur is retained by the solid carbonised briquette. On investigation, it was ascertained that, if the raw briquette charge is subjected to rapid heating, the amount of unstable sulphur will be large, whereas if it is subjected to prolonged heating the amount of stable sulphur will be large. The stable sulphur divides itself into combustible and non-combustible sulphur whilst the carbonised solid residue is being

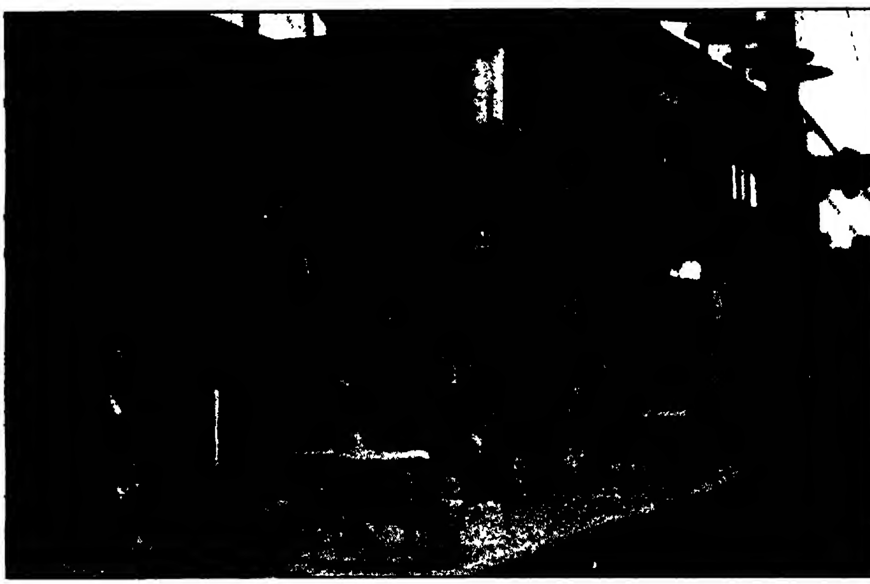

Fig 7 Hydraulic mains and anti-dip valves.

burned. The former produces the sulphurous odours in a room where it is burned To fix the stable sulphur and convert it into a non-combustible form is the most important requirement in a fuel destined for use as domestic fuel

For this purpose various kinds of fluxing chemicals are mixed with the bituminous coal used as raw material to make the briquettes. When the briquettes thus made are carbonised in a retort, the non-combustible sulphur will be increased. As fluxes, lime, oxide of iron (Fe_2O_3), magnesia, and soda are all effective. If one of these is used as material for flux, the combustibility is increased. Commercially speaking, lime is the most economical flux and is the most effective in use.

This procedure of adding flux is intended to fix the sulphur in the ash. In effecting it, it is observed that its efficiency differs according to the rate of heating during carbonisation. If the heating is rapid, the fixation of the sulphur will be more efficient than if the heating is prolonged. The quantity of the total and the fixed sulphur in the product differs according to the method used in cooling the carbonised briquettes, after the sulphur has been converted into stable sulphur during carbonisation. The following processes are applied :—

(a) Gradual cooling in a reducing atmosphere.

(b) Sudden quenching in cold water.

(c) Sudden cooling in cold water after the discharged briquettes are oxidised for a few minutes by contact with air.

By process (c) the total sulphur content is minimised. For domestic fuel, both the desulphurisation processes are applied to the briquettes during carbonising and cooling. By the preparation and carbonisation of raw briquettes, the fixation of sulphur is accomplished. The coking power of coals used as raw material and the fluxing power of the mineral constituents are carefully examined and the coals are appropriately blended. In many instances the object is attained by using a considerable amount of lime. By doing so the total amount of ash content is increased, but for domestic use in Japan the ash is no great drawback. In burning fuel in the *hibachi* (portable stove) without grate, ash is indispensable.

To summarise briefly the method of manufacture of ligno-briquettes, different blends of coal, after pre-treatment, are mixed with pitch as binder and lime as sulphur fixer, and are heated with steam and briquetted. In order to carbonise the raw briquettes thus made in a retort, they should be carbonised by rapid heating and when they are discharged a little oxidation and quick water quenching should be applied. In that way, the briquettes are made easy to ignite, their combustion is made self-supporting and without sulphurous odour, and they are made waterproof, the products thereby becoming fit for domestic use in Japan.

An example to show the difference between the raw briquettes and the ligno-briquettes is given in the following table :—

	Raw briquettes Per cent	Ligno-briquettes Per cent
Moisture	2·78	4·86
Volatile matter	38·90	11·83
Fixed carbon	49 23	70·03
Ash	11·87	18·14
Total sulphur	0·439	0·377
Combustible sulphur	0·205	0·064
Non-combustible sulphur ...	0·234	0 313

(*g*) *Gas and tar.*—The operation of the retort is intermittent and the retort is charged three times in 24 hours. Meanwhile, tar is condensed in a hydraulic main, surface condenser, and tar scrubber. The gas, free from tar, is sent into the relief holder, and then to the goose-neck of the retort bench by means of a fan, and is used for heating the retort. It is burned with secondary air pre-heated by recuperation and provides the heat for the carbonisation.

In continuous operation since 1922, it has been found that about 3,500 cu. ft. of low-temperature gas of calorific value 750 B.Th.U. per cu. ft. are produced per one ton of raw briquette charged, together with a low-temperature tar of specific gravity from

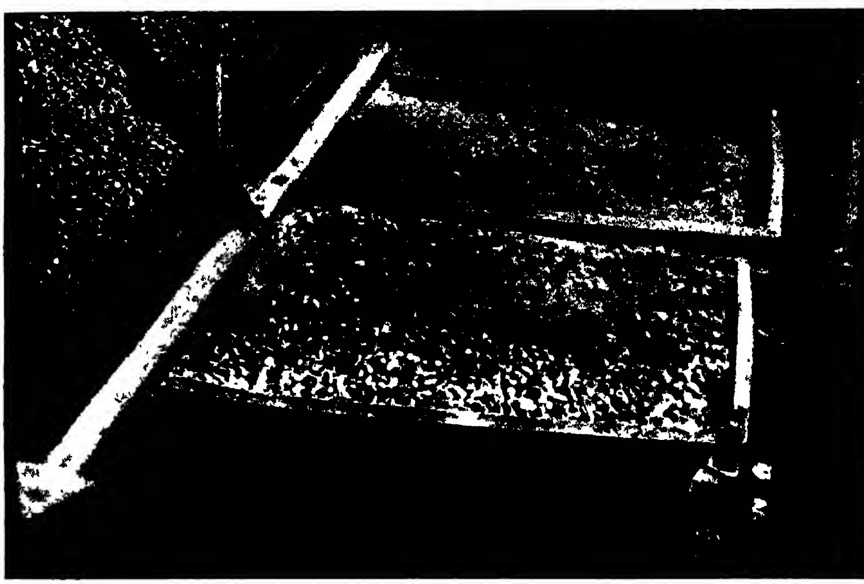

Fig. 8 Carbonised briquettes

0·96 to 1·04 at the rate of 22 imperial gallons per ton of raw briquette charged.

The gas left after the tar is scrubbed has been used for heating the retorts. In order to augment the heating power of the gas and to safeguard the practical working of carbonisation, and put the enterprise on an industrial basis, a Dawson gas producer (3 ft. in diameter) is used as an auxiliary. By the proper use of this auxiliary gas producer, the whole carbonisation system is made to work in perfect order.

The tar produced has so far been employed as wood preservative. The amount of wood preservative used in Japan has of late years considerably increased. The production of coal tar creosote has

been small and its market price has been high. In 1922, the price of 40 imperial gallons was 50 shillings. Consequently, the low-temperature tar has been used as a most economical wood preservative. The price of creosote oil has fallen somewhat recently, but the low-temperature tar is sold as a substitute for creosote at a higher price than as a substitute for fuel oil of petroleum origin.

Thus at present low-temperature tar is not used in Japan as a petroleum substitute but as a wood preservative, which is higher in price. With the extension of ligno-briquette production, the market for the tar as petroleum substitute will be expanded.

The carbonised briquettes may be seen in Fig. 8, which shows them during cooling after being quenched with water.

(*h*) *Economic data.*—The production of ligno-briquettes was started in Osaka city in 1922 and has continued there up to date, after an experiment had been made in Nagoya in 1918. The products are used chiefly as domestic fuel and for sericultural purposes.

(A) Requirements of the plant.

1. Pre-treatment of coals: Crushing machines, revolving kiln (for low-temperature oxidation and for drying).
2. Briquetting: Grinders, mixers, heater (with steam boiler), briquetting press, briquette conveyors.
3. Carbonisation: Furnaces with 14 retorts, gas producer (auxiliary for heating), gas and tar cleaning appliances, quenching and drying appliances for ligno-briquettes.
4. Stores.
5. Laboratory.
6. Office and workmen's club.

At present the plant has a capacity of 50 tons per day. At first, the work was done with six retorts. Later, the number was increased to fourteen, as at present. Up to February, 1928, ten retorts have been damaged and new ones installed.

The durability of the retorts is shown by the fact that six retorts have been operated for 58 months and have been repaired only occasionally. The total throughput of a retort is about 15,000 tons. One retort costs about 4,000 shillings (Y2,000). While cast-iron retorts are easily breakable, their renewal can be effected readily without any serious financial consideration.

(*B*) Cost of Production. Materials: Non-coking coal 61 per cent., coking coal 26 per cent., coal tar pitch as binder 11·5 per cent., lime as flux 1·5 per cent. The product is used for manufacturing the ligno-briquettes.

(a) Cost per ton of briquettes :—

	Shillings.
Labour	2·00
Fuel for revolving kilns and boilers	1·44
Purchased electric power for driving machines	0 88
Repairs and miscellaneous	0·84
Raw materials	31·00

The total cost per ton of raw briquettes is approximately 37 shillings

(b) The cost of carbonisation proper :—

	Shillings.
Labour .	2 90
Fuel and power .	2 98
Repairs and miscellaneous	1 70
Total	7 58

Besides the foregoing, the overhead expenses must be counted as 2·08 shillings per ton, so that the total cost of production of briquettes per ton is as follows :—

	Shillings
Raw briquettes	37 00
Carbonisation	7 58
Overhead expenses	2 08
Total	46 66

From one ton of raw briquettes (2,240 lb.), the following products are secured :—

Ligno-briquettes (63 per cent)	1,411 lb
Carbonised breeze (5 per cent) ...	112 lb
Low-temperature tar .	22 galls (imp)
Low temperature gas at 750 B Th U	3,500 cu ft

The carbonised breeze is sold as material for *tadon* or as fuel for *irori* in farm houses at an average price of 32 shillings per ton. The low-temperature tar is sold as wood preservative at 0·4 shillings per gallon.

All added, the net production cost of 1,411 lb. (63 per cent.) is 36·06 shillings per ton of raw briquettes treated after 1·8 shillings for breeze and 8·8 shillings for tar are subtracted from the total of 46·66 shillings of the aggregate cost of production This is equivalent to 57·24 shillings per ton of ligno-briquettes.

In view of the general expenses and profits of the enterprise, the selling price of ligno-briquettes is estimated at 120 shillings per ton. As charcoal is sold at 200 shillings per ton, the ligno-briquettes have become widely used as charcoal substitutes.

The silk industry is one of the key industries of Japan. Silks exported abroad occupy the first place among the exports of Japan. There are 2,000,000 families engaged in sericulture, that is, about

20 per cent. of Japan's total population is occupied in raising cocoons. In sericulture, 20 per cent. of the total cost of production is absorbed in keeping the proper temperature. The need of cheap fuel for the purpose of sericulture in order to reduce the cost of production has been keenly felt of late years.

The Kyoto Prefectural Sericultural Experimental Station, in May, 1927, and the Gunze Silk Manufacturing Company, in November, 1927, have recognised ligno-briquettes as excellent fuel for sericultural purposes.

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ZUSAMMENFASSUNG

Japans jährlicher Kraft- und Warmeverbrauch beläuft sich, in Geld umgerechnet, auf rund £230 000 000; die gesamte Menge Brennstoffe, auf Steinkohle umgerechnet, beträgt rund 60 770 000 metrische t; beinahe die Hälfte davon ist Steinkohle.

Während 25 Jahrhunderten konnten Holz und Holzkohle als Brennstoff für Industrie und Haushalt in Japan selbst beschafft werden. Im Laufe der Zeit nahm der Verbrauch jedoch bedeutend zu. Wenn das Abholzen der Wälder nach alter Sitte gewissenlos fortgesetzt wird, so wird der Nachwuchs den Bedarf nicht mehr decken können. Wenn sich zudem der Waldbestand im heutigen Tempo weiter verringern sollte, so wird es unmöglich werden, die Wasserkraftausnützung fortzuführen.

Doch ist es sehr schwer, lang festgesetzte Gewohnheiten eines Volkes und die Bauart der Hauser plotzlich umzuwandeln. Folglich konnte die Waldkrisis zu einem Brennstoffdilemma führen. Der Lösung dieses Brennstoffproblems, dem Japan sich jetzt gegenübergestellt sieht, widmet der Verfasser diese Abhandlung, in der er die technische und wirtschaftliche Seite der Herstellung eines neuen Ersatzmittals für Holzkohle auf Grund zehnjährigen Studiums und fünfjähriger praktischer Erfahrung auseinandersetzt.

In neunzig Prozent aller japanischer Häuser wird Holzkohle als Brennstoff verwendet, und zwar entweder auf offenem Herd ohne Rost und Schornstein, oder in tragbaren Öfen mit oder ohne Rost. Als Ersatz für die Holzkohle hat der Verfasser eine neue Sorte Brennstoff mit bituminöser Steinkohle als Rohstoff erfunden, der den besondern Verhältnissen Japans gerecht zu werden sucht. Das Herstellungsverfahren ist kurz das folgende:

1. Die rohe Steinkohle wird zuerst einer thermischen Vorbehandlung unterzogen zur Prüfung ihrer backenden Eigenschaften.
2. Dann wird sie gut vermischt.
3. Kalk wird als Flussmittel zugesetzt.
4. Man stellt pechgebunden Briketts her.

5. Die rohen Briketts kommen in einen Karbonisationsapparat mit grosser Wärmekapazität (eine senkrechte gusseiserne Retorte in einem Ofen), und werden dort einer äusserlichen und ununterbrochenen raschen Erhitzung durch das Destillationsgas aus dem Apparate selbst unterworfen, wodurch das Zusammenschmelzen der Briketts zu einer Masse verhindert wird.

6. Infolge der ununterbrochenen Einwirkung der Hitze wird der Schwefel in den mit Kalk zugesetzten Briketts entgasten Briketts in beständigem Zustande zugeführt. Letztere werden dann aus der Retorte herausgenommen. Darauf folgt während wenigen Minuten Oxydation und dann unmittelbare Wasserablöschung, wodurch der unstabile Schwefel entfernt wird.

Die so erhaltenen Ligno-Briketts bestehen aus primärem oder Alpha-Kohlenstoff und sind leicht entzündbar. Sie sind porös, zerbröckeln nicht und behalten ihre ursprüngliche Form, bis sie ganz durchgebrannt sind. Sie können also auf dieselbe Weise wie Holzkohle verwendet werden. Die beim Brennen freiwerdende Menge Schwefel ist sehr gering. Ein grosser Teil bleibt als unbrennbar in der Asche zurück. Es tritt kein Schwefelgeruch auf wie bei Holzkohle.

ATMOSPHERIC-PRESSURE BURNERS FOR NATURAL GAS

POLISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

DR. T. NIEMCZYNOWSKI

Paper No. K14

CONTENTS

Although a thorough investigation of gas burners must yield results of considerable interest, particularly to the oil industry, so far little work has been carried out on this subject.[1]

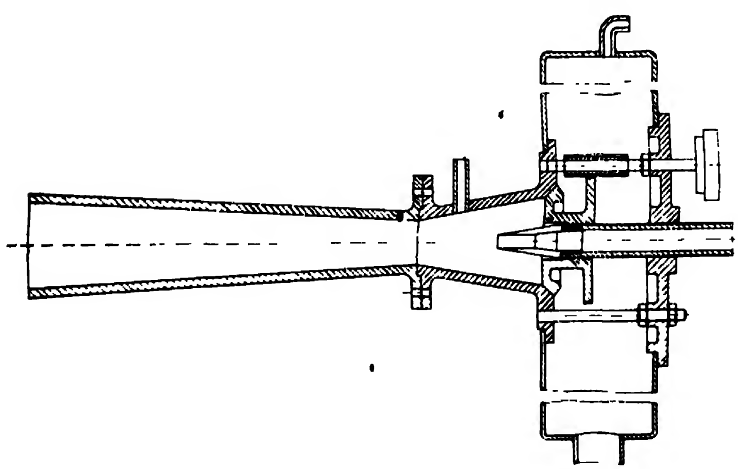

Fig. 1.

In the present paper a summary is given of the extensive investigation carried out on a specially designed gas burner (Fig. 1) at the

[1] B. T King, Chaleur et Industrie, 1922, VI. and VII.

Calorimetric Laboratory of the Technical University of Lwow, and confirmed by R. Madej, of the Government Oil Refinery at Drohobycz (Polmin). As the subject is treated theoretically, no practical details are given.

The investigation was carried out with the object of confirming a theory, which had been previously put forward, and also of determining the relationship between the dimensions, etc., and the factors influencing the behaviour of air-pressure gas burners, that is to say:—

(*a*) The quantity of gas consumed—the fuel feed (Kg. per minute),
(*b*) The quantity of air used—air feed,
(*c*) The velocity with which the mixture flows from the burner—flame velocity.

The value of these is determined by:—

(*a*) the gas pressure at the burner inlet, p_3,
(*b*) the area of cross-section of the jet in the burner, F,
(*c*) the area of cross-section of the air choke, F_2, and
(*d*) the pressure at the burner outlet, p_0 (chimney draught).

A complete investigation of the influence of design and dimensions on the behaviour of the burner should make the design of a burner suitable for various working conditions possible.

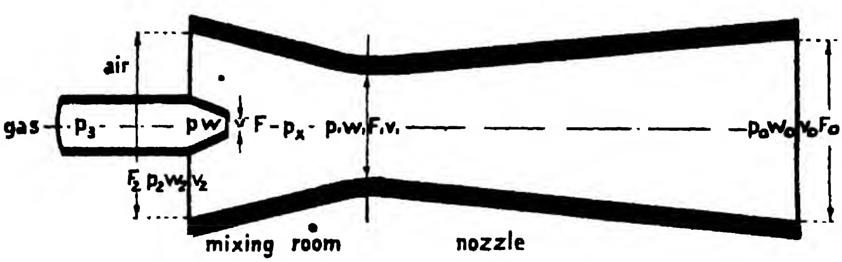

Fig. 2.

The following terminology has been adopted throughout (compare Fig. 2):—

p = pressure in Kg. per sq. metre or in metres per metre of water,
w = velocity in metres per second,
γ = specific weight in Kg. per cu. metre,
F = area of cross-section in sq. metres.
G = quantity in Kg. per second,
μ = outlet coefficient.

p_3, w_3, F_3, γ_3 refer to the gas at the burner inlet,
p, w, F, γ .. refer to the gas at the jet outlet,
$p_2, w_2, F_2, \gamma_2, G_2, \mu_2$ .. refer to the air feed,

$p_1, w_1, F_1, \gamma_1, G_1$ .. refer to the air in the widest part of the diffuser, and

$p_0, w_0, F_0, \gamma_0, B_0$ .. apply to the air at the burner outlet.

The ratios between the various areas of cross-section of the burner are given by

$$\frac{F_1}{\mu F} = m\,; \quad \frac{\mu_2 F_2}{\mu F} = n \quad \text{and} \quad \frac{F_1}{F_0} = \delta$$

Finally,

$$\sigma = \frac{G_2}{G} = \text{quantity of air admitted per Kg. of gas,}$$

$$\phi = \frac{\gamma}{\gamma_2} = \text{relative density of the gas compared with that of air,}$$

e = coefficient of resistance (approx. 1·360) and

ζ = coefficient of resistance (approx. 2·0—1·6) determined by σ.

INFLUENCE OF DIMENSIONS ON THE FIRING-RATE

The quantity of gas consumed by the burner per unit of time, given by the equation:

$$G = \mu F \sqrt{2g \frac{k}{k-1} \frac{P_3}{\gamma_3} \left[\left(\frac{P_r}{P_3} \right)^{\frac{2}{k}} - \left(\frac{P_r}{P_3} \right)^{\frac{k+1}{k}} \right]} \tag{1}$$

or, for small pressure differences, approximately by the equation

$$G = \mu F \sqrt{2g \frac{P_3 - P_r}{\gamma_3}} \tag{1a}$$

was found to be in close agreement with the results actually obtained by measurement. It therefore follows that the consumption of the burner

(1) increases with increase in gas pressure according to the parabola representing the equation (1),

(2) is proportional to the ideal section of the burner F.

INFLUENCE OF DIMENSIONS ON THE AIR FEED

From the relationship existing between the energy of the gas flowing in and that of the gas flowing out, making allowances for losses from shocks and whirling[2], it is possible to deduce the simplified equation

$$\zeta m^2 - 2mn\left(1 - \frac{n}{\phi\sigma^2}\right) + (e + \delta^2)\left(1 - \frac{1}{\sigma^2}\right) \cdot \frac{1+\phi\sigma}{1+\sigma} \cdot \frac{n^2}{\phi} = \sigma \tag{2}$$

[2] G. Zeuner. "Das Locomotivblasrohr," Zürich, 1863

showing the relationship between the excess of air used, σ, and the cross-section ratios, m and n.

By substituting for σ the values 1, 2, 3, etc., a series of curves are obtained showing the relationship between m and n when σ is equal

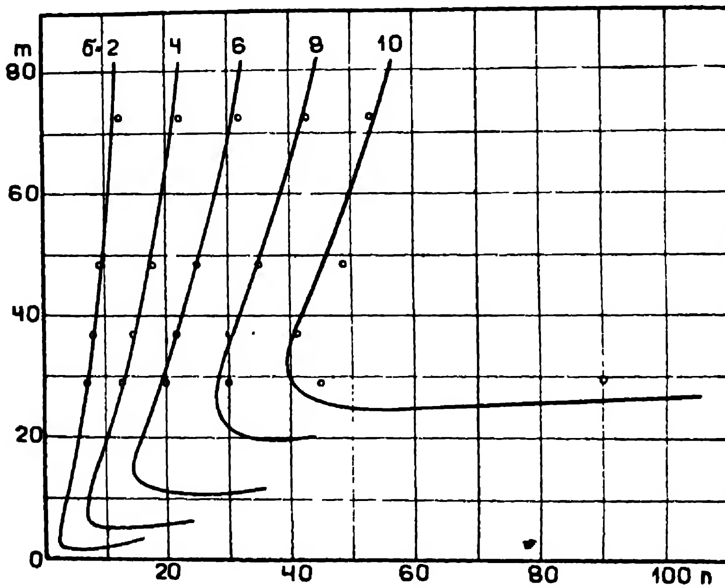

Fig. 3.

to these values (Fig. 3). A similar series of curves obtained by direct measurement is shown in Fig. 4; the two series are identical.

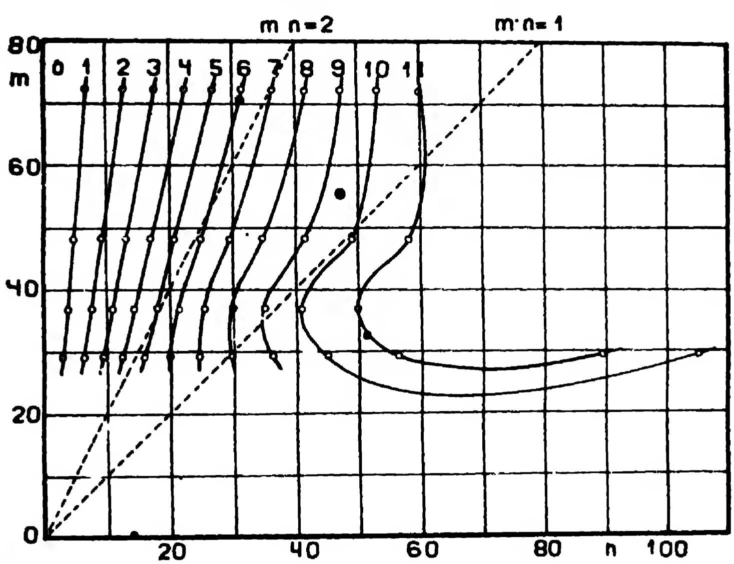

Fig. 4.

These curves show the relationship between the factors determining the amount of air necessary for any type of air-pressure burner and for any system of control irrespective of the size. They also provide a means for improving the operation of the burner by indicating the cross-sectional area allowing the largest amount of air to be used.

The burner can be regulated as follows:

(1) *By alteration of the position of the air-choke.* The jet is fixed, m being constant and n varying; regulation is effected by choking the gases (Bunsen, Hunter and N.H. burners).

The regulation curves are shown in Figs. 3 and 4 as lines parallel to the n axis. By combining certain of these lines with the curve $\sigma = f(n)$, curves are obtained indicating the amount of air necessary for burners of different dimensions (Fig. 5).

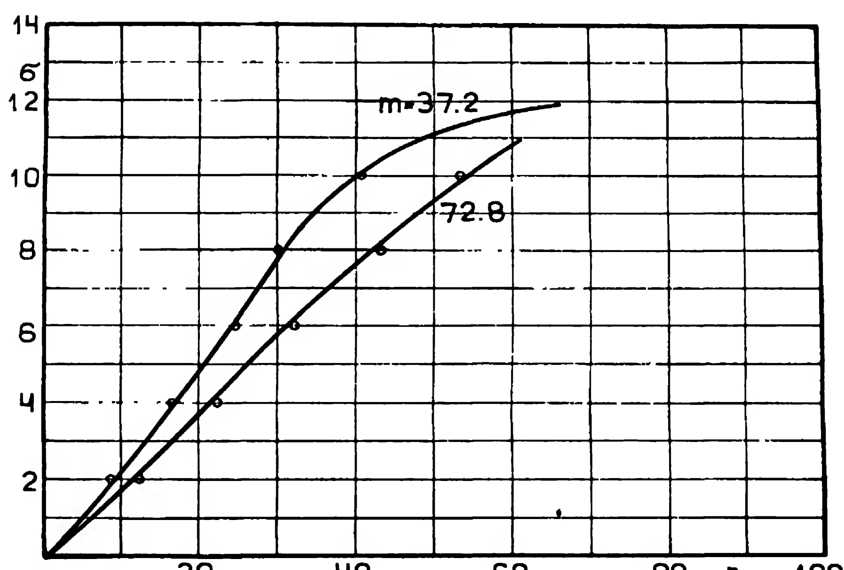

Fig. 5.

The curves obtained by direct measurement are shown in Fig. 6, and are in good agreement with those in Fig. 5. From these curves the following deductions can be made:–

(*a*) The quantity of air admitted by opening the air choke rises to a minimum; further opening results in a fall in σ.

(*b*) The direction of the regulation line depends upon the ratio of the cross section, m.

(*c*) For any given burner, *i.e.*, at a given m, there is a definite value for the choke n, which is capable of providing the maximum quantity of air

(*d*) The maximum amount of air which can be admitted is determined solely by the selection of the correct ratio for m.

(2) *By alteration of the jet size.* The burner has a definite choke opening, F_2, and the "load" is controlled by altering the size of the jet F (Merman burner).

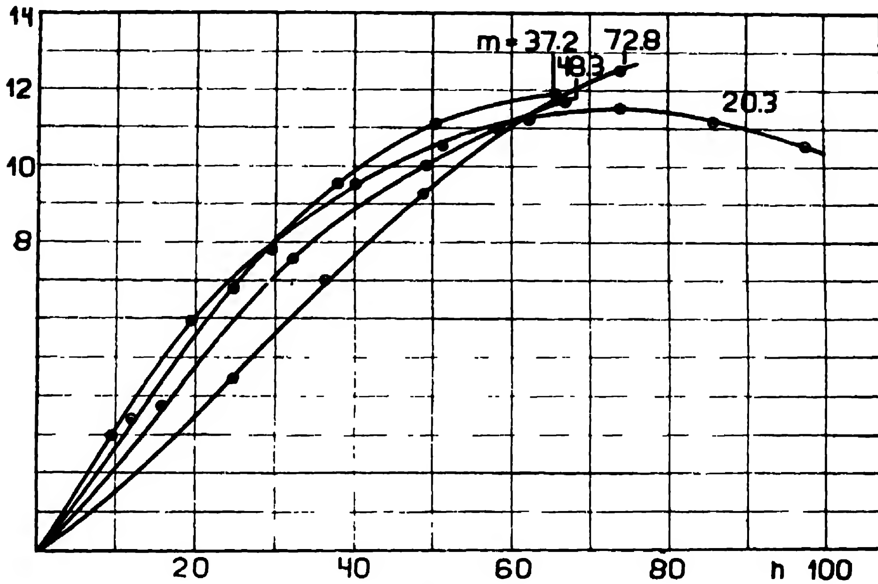

Fig. 6.

As, for this type of burner, F_1 and F_2 are fixed. m and n vary with the cross-sectional area of the jet F. The line of regulation is therefore straight and passes through the origin; it is represented by the equation

$$m = \frac{F_1}{F_2} n$$

The theoretical regulation curves are represented in Fig. 7 by the continuous lines while the regulation curve, found by measurement, is shown in dotted line. From these curves it follows that:—

(*a*) The air consumed by the burner at a definite "load" is fixed.

(*b*) The air consumed decreases with increasing "load" (m decreasing) and, conversely, it increases with decreasing "load" (m increasing).

(*c*) The direction of the line of regulation depends upon the cross-sectional areas F_1 and F_2.

(3) *By simultaneous alteration of the jet and air-choke size.* In this type of burner the gas is burnt with a constant excess of air.

With the aid of Figs. 3 and 4, values may be selected for the burner

so that, irrespective of the "load," the excess of air is constant. Any alterations in the jet size or in the air choke must then be made simultaneously in order that m and n shall correspond with the curve for σ = constant.

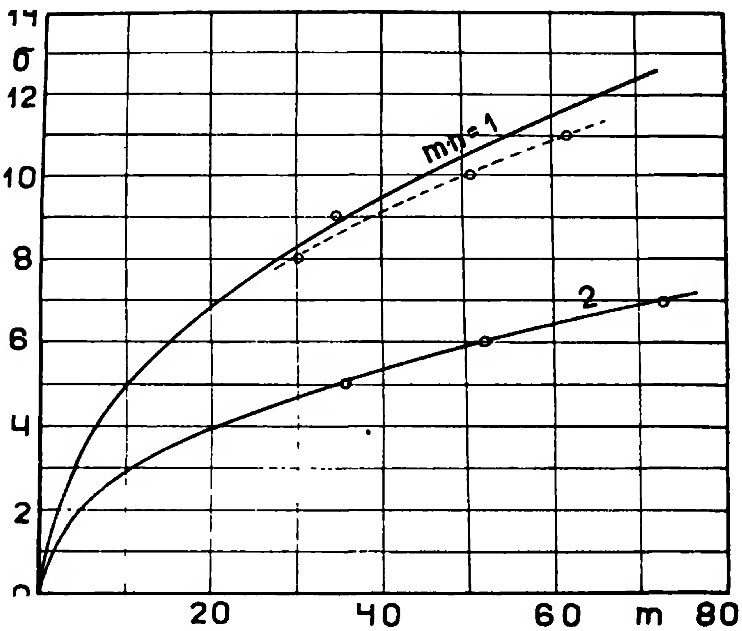

Fig. 7.

In burners not employing air suction, the so-called "atomisers" are used (Styczén, circular burners, etc.), so that $m = 0$ and $n = 0$; they are therefore represented in Figs. 3 and 4 by the origin of the co-ordinates.

Influence of Dimensions on Velocity of Flow of the Mixture from the Burner

If the velocity, W_o, with which the mixture and fixed excess of air, σ, leave the burner is too small, the flame recedes; if, on the other hand, the velocity is too great, the flame may be extinguished. The velocity is given by the equation:—

$$W_o = \frac{W}{m} [1 + \phi \sigma] \delta \tag{3}$$

where $W = \sqrt{2g \frac{P_3 - P_x}{\gamma_3}}$

The relationship between W_o and σ at constant velocity, w (the gas pressure p_t also being constant) for varying values of m is

expressed by a straight line. Fig. 8 shows the values actually found by experiment; the theoretical values are in close agreement.

The curves $m = 29{\cdot}3$, $37{\cdot}2$, $48{\cdot}5$ and $72{\cdot}8$ refer to the divergent nozzle $\delta = 0{\cdot}25$, while the curve $m = 32{\cdot}7$ refers to the cylindrical nozzle.

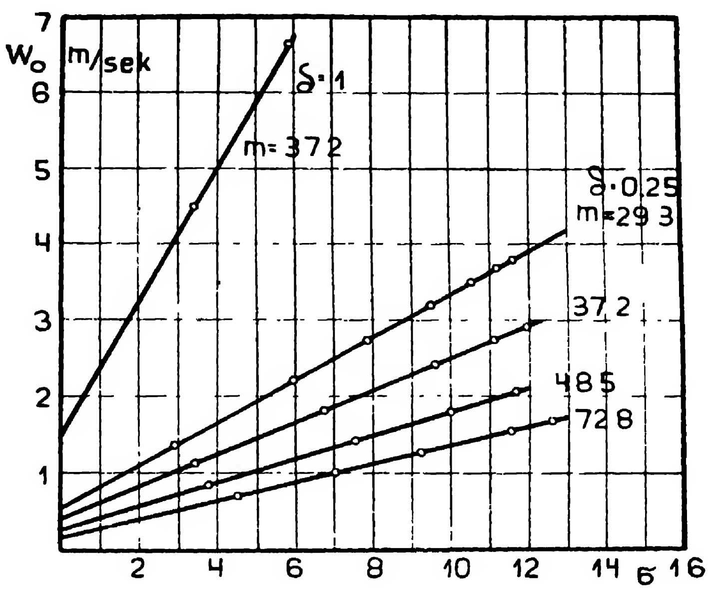

Fig. 8.

The deductions are as follows:—

(*a*) The outflow velocity increases approximately with the square root of the gas pressure at the burner inlet.

(*b*) The outflow velocity is determined by the ratio of the dimensions, m, *i.e.*, it is directly dependent upon the cross-sectional area of the jet F.

The exact values of W_0 possible with definite jet sizes and definite air excesses form the subject for an individual research.

From the data available it is possible to design an air-pressure burner suitable for natural gas as follows:—

(1) Knowing the gas pressure, p_3, and the required "load," G, *i.e.*, the gas to be consumed, by applying the outflow coefficient μ, the jet size can be calculated.

(2) After deciding upon the excess of air to be used and the value for W_0, m can be found from equation (3).

(3) From the values for W_0 and m, n, which gives the area of cross-section of the air choke F_2, can be found from Fig. 3.

With the aid of the various dimensions found and taking into account the fact that $F_0 = \frac{F}{\delta}$ a burner can be constructed, the characteristics of which are represented by Fig. 3.

Not only do the theoretical considerations given above facilitate the designing of new models, but they also allow a more complete understanding of the influence of the dimensions upon the behaviour of the burner.

ZUSAMMENFASSUNG

Es werden eingehende Versuche zusammengefasst, die mit einem speziell konstruierten Brenner ausgeführt wurden, um den Einfluss der Dimensionen und der Konstruktion auf die das Verhalten der Brenner bestimmenden Faktoren, nämlich Gaszufuhr, Luftzufuhr und Verbrennungsgeschwindigkeit, zu finden. Es wird auch angegeben, wie die erhaltenen Zahlen dazu verwendet werden können, Brenner für Naturgas unter Luftdruck jedem besondern Gebrauchszweck entsprechend angepasst zu bauen.

LOW GRADE COAL FOR BLAST FURNACE COKE

POWER ASSOCIATION OF JAPAN

DR. TSURUO NODA AND TAIZO KURODA

*Paper No. K*15

CONTENTS

INTRODUCTION

In 1912, the annual production of pig-iron was only 240,000 tons in Japan.[1] It rose to 671,000 tons and 1,240,000 tons respectively in 1922 and 1927, by which time the "coke-pig" constituted 99·1 per cent. of total pig-iron produced.

Beehive ovens, which were introduced when K. Noro started the coke industry in 1890, have now been superseded by up-to-date by-product ovens.[2]

In general the Japanese coals are of Tertiary origin and consist of highly volatile bituminous coal, which usually produces a friable coke with a porous, fingery structure. There are, of course, a few exceptions, such as Matsuura, Kyushu, and Kayanuma, Hokkaido, which produce moderately good coke.

The difficulties due to high ash and volatile contents were partially overcome by the introduction of washing and disintegration.

The development of the by-product industry in Japan was started by the establishment of sixteen Semet-Solvay coke ovens at Osaka in 1898 by K. Shimomura.[3]

In 1907, six batteries, each of twenty-five Solvay ovens were erected and started by K. Miyoshi at the Imperial Government Steel Works, Yawata, Kyushu, and they are still in operation. After

an exhaustive study of various types of oven applicable for the carbonisation of Japanese coal of high-volatility, Semet-Solvay, Koppers, Wilputte, Okamoto[4], Miike[5], and Kuroda[6] coke ovens were subsequently adopted in our coking practice, and the last named was adopted at Yawata, Honkeiko (Penhsihu), Tobata and some other districts.

Meanwhile, the studies of the nature of Japanese coking coal, especially the method of its preparation, were continued by the coke oven managers, chemists and other fuel investigators, and finally they discovered the fact that the highly volatile coal such as Futase coal, North Kyushu coalfield, should be mixed with some suitable amount of coal of low or medium volatility from Honkeiko, Kaiping or Matsuura, marking the beginning of a new epoch in the history of the Japanese coke industry.

In this paper we shall deal at some length with the general manufacture of blast furnace coke with low-grade Japanese coal, taking the examples from the coking plant at the Imperial Government Steel Works, Yawata.

COKING COAL IN JAPAN

It would be of great value if it were possible to discover some relation between the results of a proximate or an ultimate analysis of a coal sample and the character of the resulting coke. The actual nature of the coke, however, can be determined by making it on a small scale; but even such methods give only a rough preliminary idea of the coking property of the coal.

As a general rule a coking coal should contain 20 to 30 per cent. volatile matter, with a ratio of hydrogen to oxygen of about 1 : 2, and having as low an ash and sulphur content as possible.

It is unsafe to apply the results of ultimate analysis to the estimation of the coking property of Japanese coal on account of the high volatile content.

Available and combined hydrogen figures may give a useful indication for determining coking property; and coal, yielding over forty parts of available hydrogen and less than twenty parts of combined hydrogen, may be confidently expected to be of good coking quality.

In Japan this property is found only in the coals from Matsuura, Miike and Takashima. All the others which comprise the greater proportion of the Japanese coalfields are, unfortunately, so constituted as to produce a friable coke with a porous, fingery structure.

K. Kurihara gave the following figures in the estimation of the coking

power of Japanese coals by means of percentage of volatile matter present in coal[7].

TABLE I.—RANGES OF VOLATILE MATTER IN RELATION TO THE COKING POWER OF JAPANESE COALS

Coking Power.	Per cent. volatile matter. (Pure coal basis.)
Non or feebly coking	over 45
Weak coking	40 to 45
Good coking	30 to 40
Non or feebly coking	under 30

The ultimate analyses of representative coals which are now coked are shown in Table II.

H. J. Rose has classified coking coals according to the volatile content, and emphasised that the oxygen content and the calorific value should be considered at the same time when determining the coking quality of a coal. Most of the Japanese coals, except those from Matsuura and Kayanuma, are classified as highly volatile coals according to his basis.

Coal from Matsuura district in Nagasaki Prefecture, Kyushu, is one of the best coking coals in Japan, and has a moderate proportion of volatile matter and low oxygen content, but is troublesome for the manufacture of blast furnace coke on account of the quantity of interstratified material present in it and the difficulty of washing.

Coals from Miike and Futase, North Kyushu, contain over 40 per cent. and 34 per cent. volatile matter respectively. The former, which may produce a good coke, is characterised by the high calorific value and high sulphur content, being rapidly oxidised in storage, while the latter has a large amount of combined hydrogen and may produce a friable coke.

Yubari coal from Hokkaido is a typical gas coal, often containing over 44 per cent. volatile matter.

At present about 2,500,000 tons of coal are annually consumed in Japan for the manufacture of blast furnace coke, of which 1,100,000 tons are carbonised in the Imperial Government Steel Works, Yawata.

Low or medium volatile coal for admixture with the highly volatile coals constitute about 40 per cent. of the whole consumption in Japan. The detailed percentages are as follows:—

Coals from	Per cent.
Honkeiko (Penhsihu)	26·2
Kaiping	24·6
Matsuura	18·8
Shisen (Tzechwan)	3·7
Hakusan (Poshan)	3·3
Other districts	23·4

TABLE II.—ULTIMATE ANALYSES OF COALS CARBONISED IN JAPAN

(YAWATA)

Kind of Coal.	District.	Ash per cent.	V.M. per cent	F.C. per cent	P in Ash per cent	Total S per cent	N per cent.	C per cent	H per cent	O per cent.	Disposable hydrogen.	Combined hydrogen.	Calorific value (Calorie).	Fusing temperature of ash (SK).
Futase	Kyûshû (Japan)	17·61	34·52	47·87	0·015	0·517	0·62	62·73	4·31	14·48	40	29	5942	5
Miike	,,	14·85	40·23	44·92	0·048	3·920	0·59	67·89	4·69	8·96	53	16	6804	4
Takashima	,,	8·58	37·15	54·27	0·463	0·950	0·87	72·20	4·79	11·78	46	20	6999	3
Matsuura	,,	20·30	25·45	54·25	0·325	0·819	1·02	64·58	4·11	8·10	48	16	6305	11
Yûbari	Hokkaido (Japan)	5·44	44·21	50·35	0·002	0·340	1·63	73·83	5·50	13·43	51	23	7290	3
Bujun (Fushun)	China	7·53	50·36	42·11	0·174	0·710	1·26	64·52	4·48	15·54	39	30	6105	< 33
Honkeiko (Pen)	,,	20·54	21·52	57·94	0·155	0·143	0·93	66·98	3·79	6·87	44	13	6425	10-15
Kaiping	,,	14·70	31·70	53·60	0·249	1·183	1·02	72·24	4·09	7·51	44	13	6949	20-30
Hakusan (Poshan)	,,	14·63	17·52	67·85	0·011	1·030	1·41	73·21	4·33	6·42	48	11	7155	18
Doi	Karafuto (Russia)	6·55	24·80	66·90	0·751	0·450	0·85	75·64	4·44	12·02	40	19	7135	12

COAL PREPARATION

Japanese coal may never be coked as it is mined. The operations generally adopted for preparing coal for coke production may be classed as follows:—

1. Mixing.
2. Washing, including oil flotation.
3. Pulverising.
4. Stamping.

Mixing

It is very desirable, where possible, to coke individual coals and avoid mixing, owing to the difficulties introduced, both in the preparation and also in the ovens, owing to the unequal fusing temperature.

Coals are mixed in all the Japanese and neighbouring plants, except that at Honkeiko (consisting of sixty Kuroda regenerative ovens), which makes a good blast furnace coke from the single coal mined there.

At Yawata, Futase coal is chiefly carbonised mixed with coal from Kaiping or Honkeiko, China, to the extent of between 20 and 30 per cent. The anthracitic coal from Shisen or Shinko, China, has lately been mixed with Futase and Matsuura coal, a small amount of pitch often being added.

Table III. shows the approximate analyses of the several kinds of coal charged in ovens at the plant of Yawata.

Washing

Most of the Japanese and Chinese coals, which are now actually carbonised, must be washed in order to reduce the ash and sulphur content, which are too high to make a good metallurgical coke.

The large amount of interstratified materials present affects the efficiency of the preparation and gives rise to quantities of "middlings."

Futase coal of 14·68 per cent. ash was crushed so as to pass through a 40 mm. screen, and the results of the washing operation are given in Table IV.

The middlings yielded in the primary test were again crushed under 10 mm. size, rewashed, and the results of washing were obtained as in Table V.

The recovery of coking coal from middlings was proved to be a failure.

In the float and sink analysis of coking coals, we obtained the results shown in Fig. 1.[8]

TABLE III.—ANALYSES OF COAL CHARGED IN OVENS (YAWATA)

Coal-mixture.	Moisture present in charging coal.	Air-Dry Basis.					
		Moisture.	Ash.	V.M.	F.C.	S.	N.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
70% Futase, 30% Matsuura.	12-15	1·49	11·02	31·10	56·39	0·59	1·09
80% Futase, 20% Honkeiko.	,,	1·44	11·05	32·42	55·09	0·63	0·92
70% Futase, 30% Kaiping.	,,	1·53	11·49	32·21	54·77	0·73	0·96
60% Futase, 30% Matsuura, 10% Shisen	,,	1·33	14·01	32·74	51·92	0·61	1·18
80% Futase, 20% Doi.	,,	1·59	10 51	32·32	55·58	0·52	1·05
60% Futase, 30% Matsuura, 10% Shinko.	,,	1·30	10·20	32·06	56·44	0·53	1·00

TABLE IV.—WASHING TEST OF FUTASE COAL OF 14·68% ASH

Size. mm.	Raw Coal. Per cent.	Coal.		Middlings.		Refuse.	
		Yield per cent.	Ash per cent.	Yield per cent.	Ash per cent.	Yield per cent.	Ash per cent.
40-20	23·65	16 70	10·20	4·77	29·10	1·86	64·85
20-10	20·34	16·69	9·60	2·25	32·00	0·92	68·15
10-6	17·54	15·04	8·85	1·33	29 40	0·90	63·15
6-0	38·47	31·09	7·63	2·71	27·10	3·05	57·40
Slurry	—	2·12	21·55	—	—	—	—
Loss	—	—	—	0·57	30·20	—	—
	100·00	81·64	9·15	11·63	29·27	6·73	61·70

TABLE V.—WASHING RESULTS OF MIDDLINGS OF 29·27 PER CENT. ASH

Coal. mm	Coal.		Middlings.		Refuse.	
	Yield per cent.	Ash per cent.	Yield per cent.	Ash per cent.	Yield per cent.	Ash per cent.
10-6	1·54	20·10	0·80	43·40	0·75	54·85
6-0	5·37	17·10	1·17	41·40	1·60	56·60
Slurry	0·40	21·55	—	—	—	—
11·68%	7·31	17·97	1·97	41·80	2·35	56·04

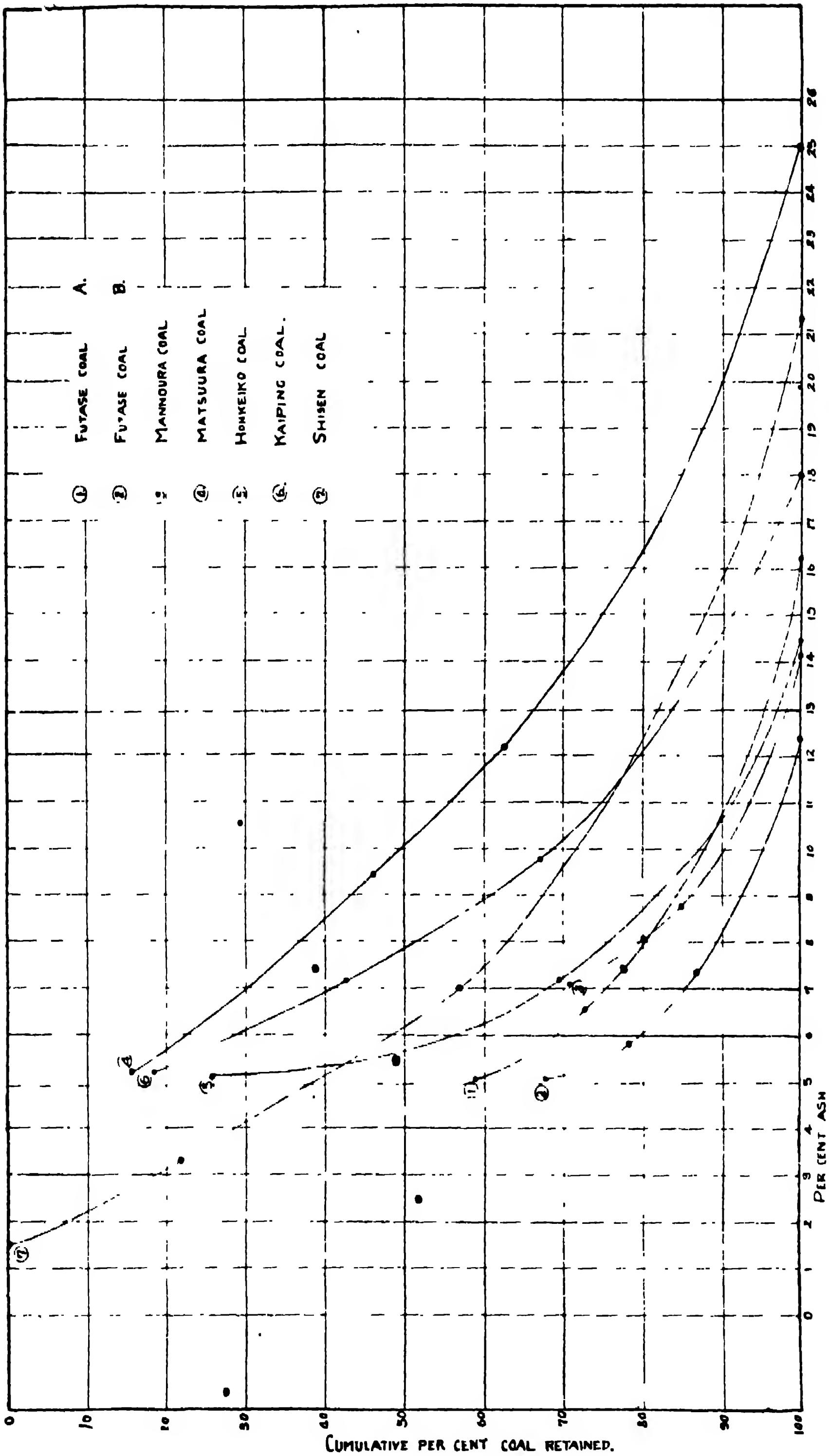

Fig 1 Relation between cumulative yield of coal retained and per cent ash in coal.

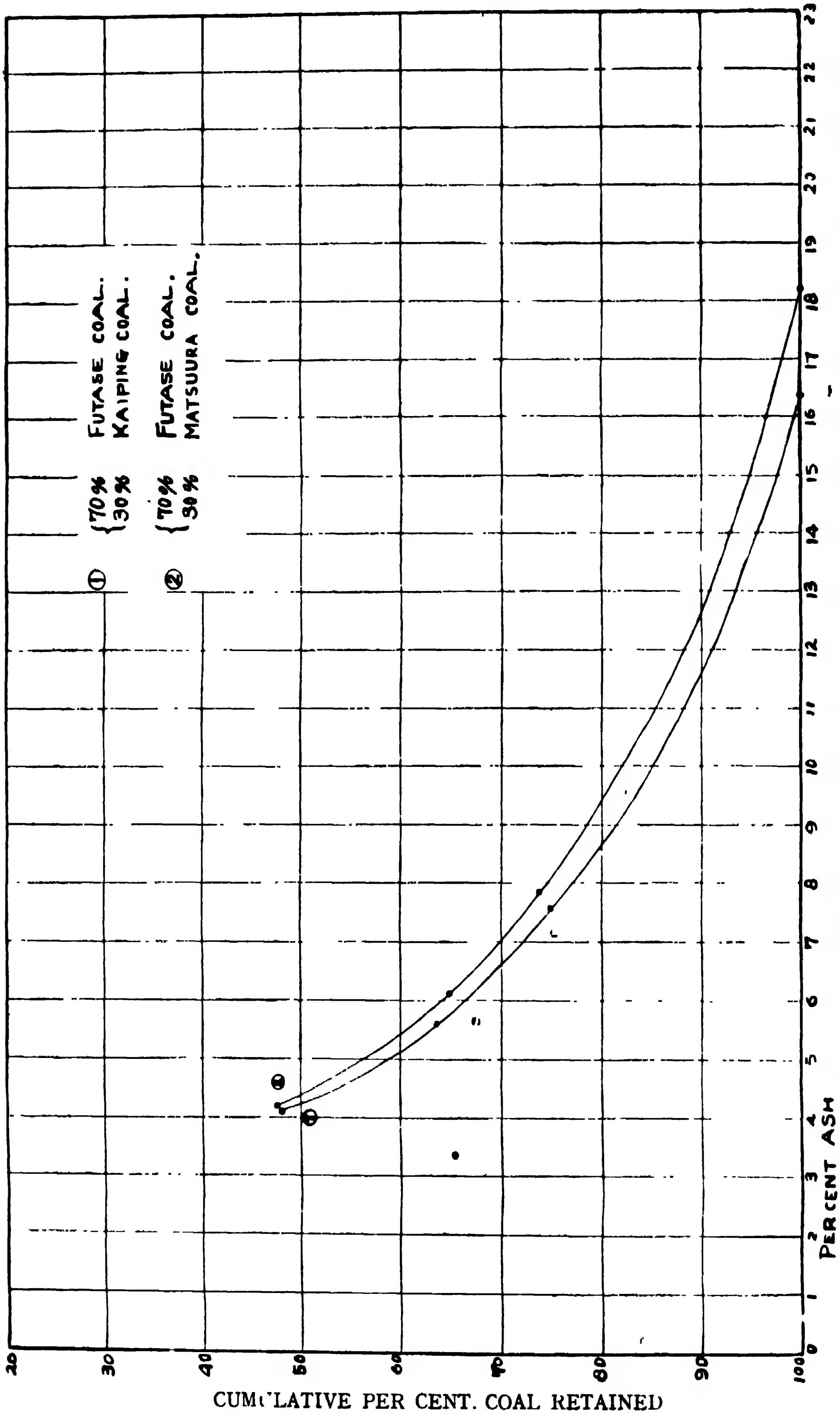

FIG 2. RELATION BETWEEN CUMULATIVE YIELD OF COAL AND PERCENT ASH IN THE CASE OF MIXTURE

If a washed coal of 10 per cent. ash is required, the cumulative percentage of coal retained is shown to be as follows:—

Coal.	Cumulative wt. per cent. of coal.
Futase A.	88·0
Futase B.	95·0
Matsuura	50·0
Honkeiko	86·5
Kaiping	67·5
Shisen	71·0

In the case of a mixture of 70 per cent. Futase coal and 30 per cent. Matsuura coal, or that from Futase and Kaiping in the same proportion, we find up to 20 per cent. loss of coal. In practice this would be more (Fig. 2)

From the standpoint above described, about 12 per cent. ash in washed coal is estimated as a standard in Yawata, though less, even under 10 per cent., is generally desired for blast furnace use. Previous to washing, the coal always requires a certain amount of crushing, *e.g.*, so as to pass through a 40 mm. screen.

Table VI. shows the annual working results from the washing plant at Yawata.

TABLE VI.—THE ANNUAL WASHING RESULTS (YAWATA)

Year	Ash in raw coal per cent	Washed Coal		Refuse		Tailing from slurry per cent
		Yield per cent	Ash per cent.	Yield per cent	Ash per cent	
1918	17·75	81·9	10·51	15·8	54·26	2·3
1919	19·25	79·9	9·74	17·9	60·99	2·2
1920	21·07	75·3	10·92	22·2	55·06	2·5
1921	20·15	79·7	11·06	18·0	59·78	2·3
1922	18·80	81·1	11·00	17·2	55·03	1·7
1923	19·12	81·9	11·90	16·5	50·52	1·6
1924	19·20	83·2	11·90	15·4	58·12	1·4
1925	18·90	84·5	11·60	14·6	60·82	0·9
1926	15·92	90·6	11·38	9·0	61·21	0·4
1927	16·57	92·1	11·98	7·6	71·92	0·3

The froth flotation process for the purpose of recovery of available coal from slurry was first operated in 1921[9]. The decrease of tailing rejected may be attributed chiefly to the installation of this process. (Table VI.) In this process, the raw slurry (24·17 per cent. ash) is separated into 78·5 per cent. froth (10·96 per cent. ash), afterwards to be mixed with washed coal and 21·5 per cent. tailing (70·33 per cent. ash) to be rejected.

The annual total amount of refuse in Japan may rise to about 300,000 tons, and that of slurry to 50,000 tons.

At present, the slurry is partly admixed with washed coal charged into the oven and also consumed in steam boilers or briquetted.

Only a small portion of the refuse is consumed in boiler plant or used for the purpose of coating of charges in beehive oven. In the Yawata Steel Works, the refuse is rewashed and utilised for briquette-making.[10]

The washing systems employed in Japanese practice at present are principally of the wet type, such as Luhrig, Baum, or Humboldt, the capacities of which are mostly between 10 tons and 80 tons per hour[11].

PULVERISING

In the carbonisation of Japanese coals a certain degree of pulverisation is often profitable for efficient results in the production of high-grade metallurgical coke.

At Yawata, the washed coal is crushed so as to give the following products:—

	Per cent.
Through 2/8 in.	90
Through 3/8 in. and on 2/8 in. ...	4
On 3/8 in.	6

In addition, a considerable amount of slurry is added to the charge. This has proved to be effective in increasing the strength of the coke[12].

STAMPING

It is known that stamping always makes a coke hard, especially when it is made from highly volatile coal; but lately this practice has been generally abandoned owing to the increasing height and decreasing width of the coking chamber.

COKING PRACTICE

The recent development of coke oven construction has considerably enlarged the coking possibilities of the highly volatile or low-grade Japanese coal.

At Yawata 200 Kuroda regenerative ovens, 150 Semet-Solvay ovens, and 120 Koppers ovens are now in operation, which produce about 600,000 tons of blast-furnace coke annually.

In by-product coke ovens, the operating temperature is generally measured at about 1,100°C. to 1,200°C., and rarely at 1,300°C. or more in the heating flues[13].

For this reason the narrow coke oven will be generally adopted in

Japan in the near future, although at present those of 400 mm. to 500 mm. width are mostly used, with the exception of the 350 mm. ovens of the Tokyo Gas Co.

The capacities and the coking hours of representative types of coke oven in Japan are shown in Table VII.

TABLE VII.—CAPACITIES AND COKING HOURS OF OVENS IN JAPAN.

Types of oven.	Coal charged per oven.	Coking time.
	tons.	hrs.
Wilputte	11·5	21-24
Kuroda	10-11	24
Muke	11	28
Koppers	8-8·5	33-36
Solvay	6-7	28-30
Coppee	5	48
Okamoto	3	36

One ton of coal charged into the oven produces about 300 cu. m. of gas of 4,000 cal. per cu. m., of which one-half or two-thirds are used for the oven heating and the surplus gas is supplied for:—

I. Town Supply
II. Steam-raising plant
III. Steel plant
IV. Gas engine
V. Dryer

In the modern iron and steel plant, coke oven gas as rich as 4,000 cal. per cu. m. should be supplied to the plants where higher temperatures are required, such as open hearth and reheating furnaces, etc., and for town's use, while the coke oven is heated with blast furnace gas[14].

At Yawata 4,000 cu. m. of blast furnace gas of 850 cal. per cu. m. is actually produced per ton of pig, which is now consumed in hot stoves, boilers, and gas engines.

TABLE VIII.—GAS ANALYSES (YAWATA).

	CO_2.	O_2.	C_2H_4	CO.	CH_4.	H_2.	N_2.
Coke oven gas	4·7	0·6	3·8	7·8	26·0	40·7	16·4
Blast furnace gas	10-12	0-0·1		27-30	Trace -1·0	1-2	60

In the near future, it is intended to use blast-furnace gas in the coke ovens in place of the coke-oven gas.

COKE

The coal consumptions per ton of coke produced in the Yawata coking plant during last ten years are shown in Fig. 3 on an annual average.

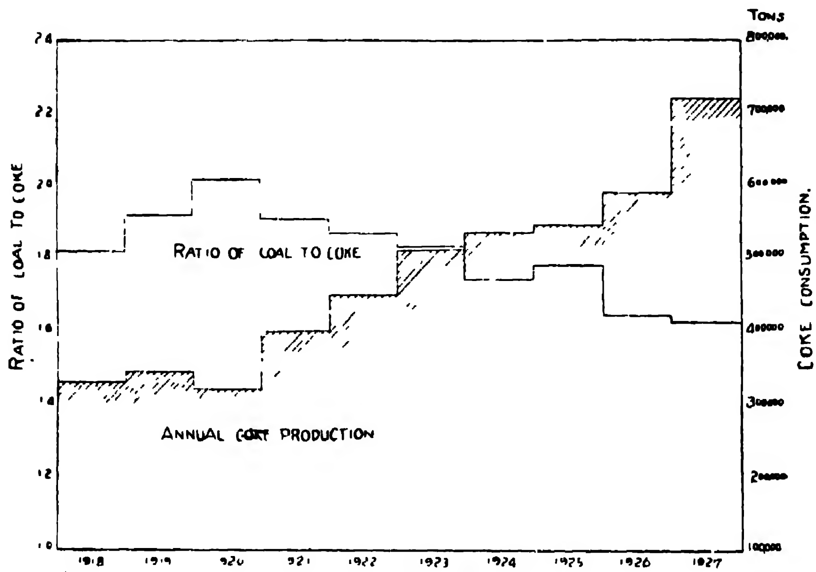

Fig 3 Coke Production and Ratio of Coal to Coke in the Coking Plant of The Imperial Government Steel Works (Yawata)

The increase of the efficiency of washing and coking have reduced the ratio of the consumption of raw coal to coke year by year.

At Yawata, the following was the specification of the coke as produced in 1924·

		Per cent.
Drum Test	over	85·00
Ash	less	18·99
Porosity	over	41·00
Fixed Carbon	over	80·00

The compressive strength test or the shatter test are often adopted for the determination of the strength or hardness of coke. At Yawata, however, these tests are not used for everyday purposes, because large errors often occur in the case of small samples, especially in such fingery brittle coke as ours.

We have therefore started a special compound strength test—the so-called "Drum Test"—to examine the resistance of coke to impact and abrasion, which is of great practical value.

Sketch of Drum.

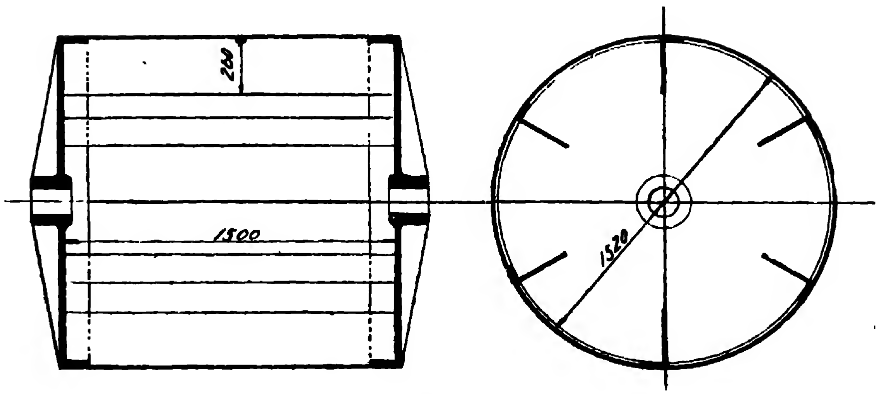

Fig 4.

The test may be carried out in an iron cylindrical drum of 1·52 m. in diameter and 1·5 m. in length, inside of which six steel blades are fixed longitudinally.

Immediately after quenching, five pieces of coke of about 2 Kg. are charged into the drum, which is rotated at a rate of 15 r.p.m. After thirty revolutions the sample is discharged from the drum and sieved through a 15 mm. sieve (square openings). The percentage remaining on the sieve in relation to the total sample gives a fairly reliable indication of the resistivity of the coke to impact and abrasion.

The drum test of the coke produced from single Futase coal gave the following results:—

	On 6 mm.	On 10 mm.	On 15 mm. (Standard Sieve)	On 20 mm.	On 40 mm.
Per cent.	90·66	87·69	77·69	22·30	0

From the above figures, it may be assumed that the coke from Futase coal would be crushed down to the degree of fine breeze by impact or abrasion when charged to a blast furnace.

TABLE IX.—RESULTS OF "DRUM TEST."

Coke from	(Yawata) Per cent. on 15 mm.
Futase coal	70–78
Matsuura coal .	92–96
Kayanuma coal .	95
Takashima coal .	85–88
Miike coal	80–85
Yubari coal	75–80
Kaiping coal . . .	90
Hakusan (Poshan) .	95
Houkeiko (Penhsihu)	95
Doi	92–95

Among the coals of low volatile contents consumed in the Yawata coking plant, Kaiping coal constitutes the largest proportion; but its quality as coking coal is not so good as Hakusan and Honkeiko.

Matsuura coal resembles closely that from Kaiping in the ultimate analysis (pure coal basis), but usually produces a coke of comparatively stronger structure.

The coke from a mixture of 20 per cent. Kaiping coal and 80 per cent. Futase coal, coked in a Semet-Solvay by-product oven, shows just above 85 per cent. in the drum test, and the greater the proportion of Kaiping coal the greater the strength of the product, but the rate of increase is gradually reduced up to a 40 per cent. admixture of Kaiping[15] coal.

In place of Kaiping coal, Matsuura can be used and shows better results, similar to the comparative results when they are carbonised separately.

Ash

At the Yawata coking plant about 18 per cent. ash is allowed in the coke[16]. Unfortunately, we have no experimental data to explain the relation between the amount of ash and the strength of coke. In some cases, the fine mineral materials uniformly distributed in coal may actually strengthen the cell structure of coke. As a general rule, however, it will be easily recognised that the opposite relationship is found between the ash content and the strength of the coke.

The general relationship between these factors is shown in Fig. 5, on which the working data at Yawata is plotted.

While the amount of ash present in the coke has shown little fluctuation throughout these ten years, the smaller the percentage of Futase coal consumed, the greater seems to be the strength of the coke.

Porosity

The highly volatile matter in Japanese coals tends to produce a coke of high porosity, but its strength is low. They must accordingly be admixed with low or medium volatile coal in order to produce cokes of moderate porosity and higher strength for blast furnace purposes. The blast furnace operators in Japan prefer a strong coke to one of greater porosity and higher combustibility.

Sulphur and Phosphorus

These constituents are wholly dependent upon the nature of the coal. For blast furnace coke, generally less than 1 per cent. sulphur and 0·01 per cent. phosphorus is desired for Bessemer or acid pig, while for basic pig the phosphorus content is of less importance. These conditions are easily fulfilled.

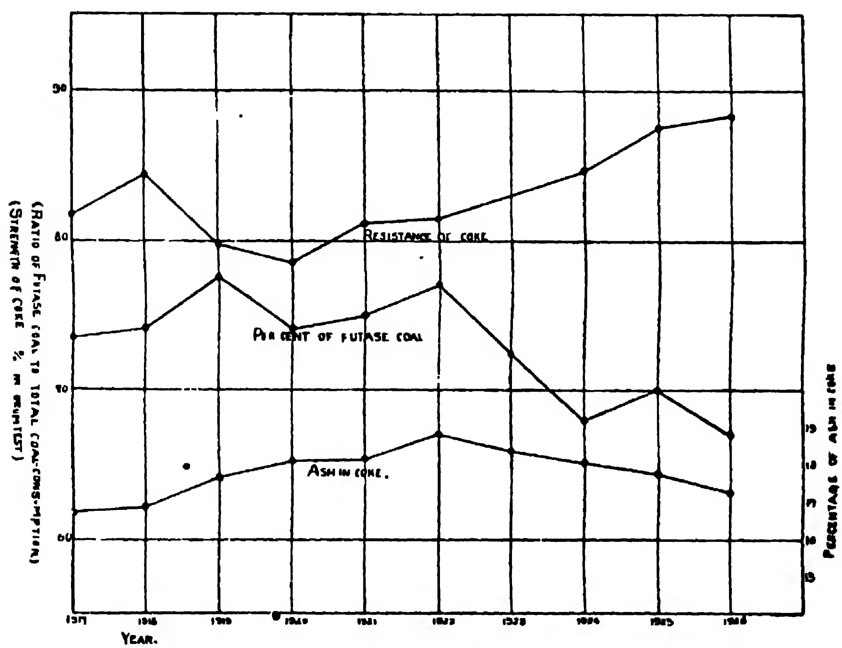

Fig 5 Some Relationship between Strength of Coke and Per cent. of Futase Coal.

Coke Size

The constant uniformity of coke size and of quality are essential to economical blast furnace operation.

In Japanese practice, the size of blast furnace coke generally lies between 30 mm. and 80 mm. The small sized coke, which passes through a 20 mm. or 25 mm. sieve is treated as breeze.

Table X shows the characters of some representative coke produced from the coke oven plant at Yawata, on an annual average to 1926.

TABLE X.—BLAST FURNACE COKE (YAWATA).

Kind of coal carbonised.	Ash per cent.	F.C. per cent.	Drum Test per cent.	Porosity per cent.	True Sp. Gr.
70% Futase, 30% Matsuura	17·37	81·98	87·95	44·52	·68
80% Futase, 20% Honkeiko.	16·82	82·65	89·37	45·82	1·67
70% Futase, 30% Kaiping	17·31	82·05	86·90	46·16	1·68
60% Futase, 30% Takashima 10% Shinko.	14·15	85·13	83·67	44·27	1·67
80% Futase, 20% Doi, 20% Karafuto.	15·94	83·27	88·86	43·71	1·63
60% Futase, 30% Matsuura, 10% Shisen.	17·85	81·34	84·06	43·66	1·64
60% Futase, 30% Matsuura, 10% Shinko	16·58	82·53	85·34	44·42	1·65

BY-PRODUCT RECOVERY

By-products and their recovery are factors directly essential to the economical operation of coke ovens, especially in conjunction with iron and steel plants. The by-product coke oven plants at Yawata produces the following primary or secondary by-products at the present time:—

Raw coal (100)
- Tailing from slurry (0·4)
- Coking coal (90·6)-100 ——————
  - Lump coke (66·96)
  - Breeze (3·16)
  - Gas (300 cu m. per ton of coal)
  - Light oil (1·12)
  - Ammonium sulphate (1·04)
  - Tar (4·37)
- Refuse (9·0)-100 —
  - Coal (25)
  - Dirt (75)

Light oil
- Pure benzol
- Pure toluol
- 100% benzol
- Motor benzol
- Solvent naphtha
- Xylol

Tar
- Hard pitch
- Soft pitch
- Creosote oil
- Naphthalen
- Phenol
- Cresol
- Pitch coke
- Anthracene
- Tar oil
- Tar anhydrous.

Among these by-products, ammonium sulphate and benzol, or motor benzol to which recent attention has been paid, are of the utmost importance. The general range of by-products in the manufacture of blast-furnace coke, however, may be represented by the following figures:—

	Per cent.
Coke	60-68
Tar	2·8-5·2
Amm. Sulphate	0·9-1·16
Benzol	0·62-1·00

That is to say, in the carbonisation of Japanese coals, a comparatively small amount of ammonium sulphate and a somewhat large amount of benzol derivatives will be obtained, on account of the highly volatile matter and low proportion of nitrogen present.

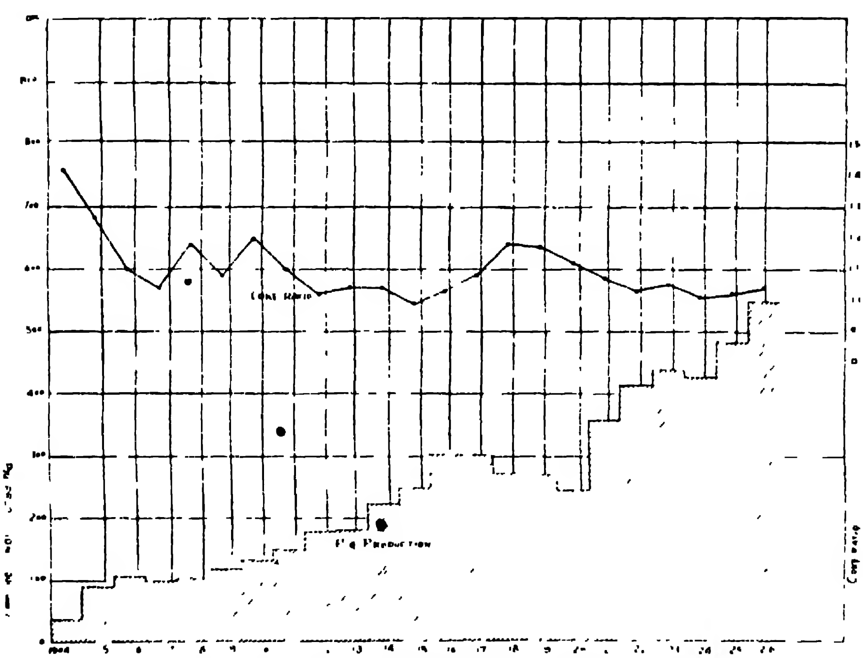

FIG. 6. Annual Pig Production and Coke Ratio (Imp. Gov. Steel Works, Yawata.)

BLAST FURNACE PRACTICE

At Yaw ta, 52 per cent. iron ore, 33 per cent. coke, 13 per cent. limestone and 2 per cent. manganese ore are charged into six blast furnaces, which are producing annually about 580,000 tons of pig-iron.

The development of blast furnace design, together with the improvement of coke quality, has been the cause of more efficient results year by year.

Fig. 6 shows the ratio of coke to pig-iron during the recent years, and we can also see the progressive tendency of the blast-furnace operation in Table XI., taken as an example of No. 1 blast furnace at Yawata.

TABLE XI.—WORKING RESULTS OF NO. 1 BLAST FURNACE AT YAWATA.

	Inner volume of blast furnace.	Volume per ton of pig produced.	Daily production.
	cu. m.	cu. m.	tons.
1st period	493·9	6·46	76
2nd ,,	479·8	3·32	145
3rd ,,	479·8	2·71	162
4th ,,	440·0	2·21	201
5th ,,	444·6	2·05	217
6th ,,	444·6	1·83	243

In the case of No. 1 blast furnace, the internal volume has been somewhat reduced, but the pig-iron production per unit time has been increased.

The internal volumes of No. 5 and No. 6 blast furnaces have reached a figure of 575 cu. m., and the daily pig-iron production has been recorded as high as 420 tons.

The blast furnaces at Yawata consume 4,000 cu. m. of hot blast at 600°C. and 700°C., and under 500 to 600 gm. per sq. cm. per ton of pig.

GENERAL CONCLUSION

It will be well recognised from this paper that Japanese coking coals are of a low grade, which generally produce a porous friable coke.

In brief, the general conclusions as to the manufacture of the blast furnace coke from Japanese coal of high volatility or high oxygen contents may be summarised as follows:—

1. In the carbonisation of Japanese low-grade coal, there exist two essential operations, of which one is coal preparation and the other the heating process.

2. The operations generally used for preparing coking coal may

consist of four elements—mixing, washing, pulverising, and stamping—which have been well studied in Japan.

3. Low or medium volatile coal from China, Karafuto or a part of Japan, and anthracite coal from Shisen or Shinko, China, are generally admixed with Japanese high-volatile coal.

In the case of anthracite coal, a small amount of pitch is often added.

4. The lower the percentage of ash, the better the coke. It is necessary, however, to allow a comparatively high percentage of ash in the washed coal on account of the high ash content and a large amount of middlings in raw coal, in addition to the considerable loss of available coal in washing practice. After careful consideration of both blast furnace and washing operation, about 12 per cent. ash in the coal or 18 per cent. ash in the coke respectively is estimated as the most economical at Yawata.

5. The recovery of available coal from slurry and refuse has been under consideration, and for this purpose the froth flotation process and the rewashing plant have since been adopted.

6. The construction and the installation of various types of by-product oven has caused a decrease of the cost of coke-making, accompanied by large increase in by-products yielded.

7. For the coking of Japanese coal, rapid coking seems to be most profitable, and it may be possible to produce in this way good metallurgical coke.

8. The development of blast furnace design, such as the enlargement of hearth area and the increase of bosh angle, together with the improvement of coke quality, has caused an enormous increase in pig-iron production per unit volume of furnace.

A comparatively good coke suitable for blast-furnace operation is being produced from low-grade Japanese coals by means of coal preparation and a suitable heating operation.

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ZUSAMMENFASSUNG

Es wird aus diesem Berichte klar erkannt werden, dass japanische Kohlen fur die Herstellung von Koks alle minderwertig sind, und dass im allgemeinen nur poroser und leicht bruchiger Koks zubereitet werden kann.

Der Betrieb der Verkohlung minderwertiger japanischer Kohlen umfasst die folgenden zwei wichtigen Funktionen. erstens die Kohlenvorbereitung und zweitens das Erhitzungsverfahren. Das allgemein gebräuchliche Verfahren für die Vorbereitung der Kokskohlen besteht aus den folgenden vier Stufen: die Mischung, die Waschung, die Pulverisierung und das Stampfen; alle diese sind in Japan weitgehen erforscht worden.

Es wird nun moglich, durch passende Kohlenvorbereitung und Erhitzungsoperationen aus unseren minderwertigen Kohlen einen verhaltnismässig guten Hochofenkoks zuzubereiten.

THE HYDRAULIC THEORY OF THE MOVEMENTS OF GASES AS APPLIED TO THE CONSTRUCTION OF FURNACES

RUSSIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

*Paper No. K*16

CONTENTS

PART I.—OPERATING PRINCIPLES OF A WELL DESIGNED DRYING KILN

PROF. W. E. GROOM-GRJIMAILO

When a stream of hot dry air strikes a wet surface it effects the evaporation of moisture from that surface, and in the course of this process, as the relative humidity of the air increases, it cools and becomes relatively heavier than hot dry air. The difference in density of cold moist and hot dry air causes a downflow of the former.

Provided that the natural descending stream of cold moist air is not interfered with, and a supply of hot dry air is admitted to the upper part, we shall obtain an adequate design for a single-stage saturation drying kiln.

Although drying kilns constructed in such a way would work satisfactorily and might secure uniform drying, they require a large expenditure of fresh warm air and the heat losses associated with the warm air discharged from the kiln are considerable, their efficiency for that reason being very low.

Better results are obtained by reheating the cold humidified air, which has descended to the bottom of the kiln, and leading it again into the upper part of the kiln. There the air again strikes the wet surfaces, and now having an increased moisture content and lower temperature it again descends to the bottom. This process may be repeated several times until the relative humidity of the air at the bottom reaches a figure conforming with technical efficiency but, of course, varying within the limits of 40 to 95 per cent., depending upon the kind of material to be dried.

In many systems of drying kilns, forced circulation for the repeated humidification of air is applied by means of fans. Air from the kiln is forced to heating units, from which it passes again to the kiln and so on. On the way part of the moist air is let out into the surrounding atmosphere, being replaced by a corresponding volume of fresh air.

The same effect may be produced by arranging the heating units along the walls at the bottom of the kiln. In this way, cold moist air which has descended to the bottom would be reheated by the radiators, and becoming lighter, would ascend again to the upper part of the kiln. Thus a natural circulation of air will be induced (see Fig. 1). Screens on both sides of the material to be dried are arranged in order to control this circulation as well as for imparting the requisite velocity to the air. Various authors have found it desirable to maintain the rate of circulation on the surface of material to be dried at at least 0·2 to 0·4 metres per second to ensure rapid drying. These rates may be easily secured by the method of producing the circulation described above.

The difference in specific weight of the air when heated and the air cooled and humidified within the pile of drying material, is the physical force which promotes that circulation. This difference is absorbed by the resistances to the current of circulating air on its way through the kiln.

Theoretical calculations, subsequently supported by numerous experiments, have shown top and bottom temperatures (t max.—t min.) to be the functions of those resistances which the circulating air encounters on its way.

The resistances comprise the following items:—

1. The resistance within the pile of material subjected to drying.
2. „ „ the heating units.
3. „ „ the space below the pile of dried material.
4. „ „ the space between the screens and the walls.
5. „ „ the space above the drying material and below the ceiling.

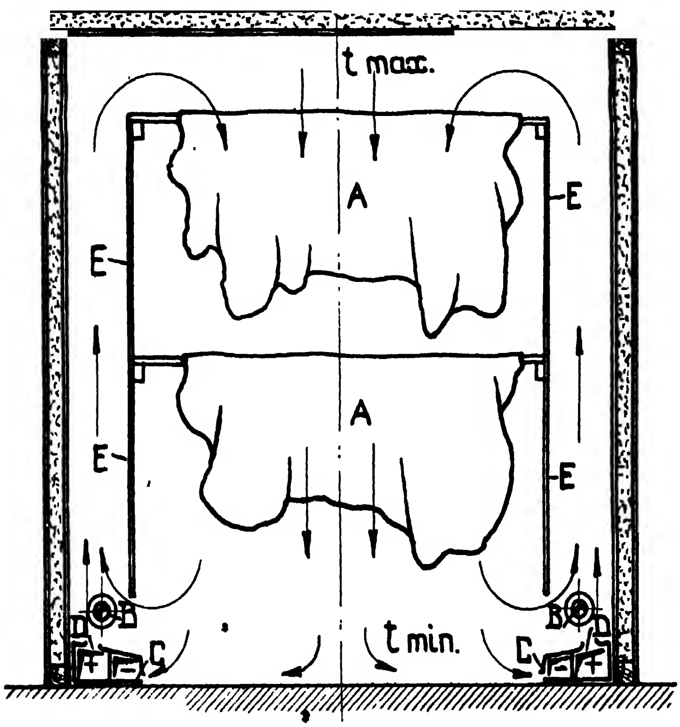

Fig. 1.

AA—Leather. BB—Radiators. C—Exhaust air duct. D—Inlet of fresh air. EE—Screens.

If the kiln is of proper design and the material to be dried is properly piled, the difference in top and bottom temperatures will not exceed the limits of a few degrees centigrade, but this small difference is quite sufficient to impart a proper rate of air circulation through the pile of material.

On the other hand, by irregular and excessively close piling or by the contraction of the air stream in the heating units, that difference may increase up to 10°C. and even more.

The extent to which air is saturated within the kiln largely depends upon the amount of the air removed. If large volumes of moist air are discharged, they are replaced in the kiln by a corresponding volume of fresh, dry air from outside, and the humidity of the inside air accordingly drops.

Thus, the operation of a drying kiln designed in this way is within full control. The proper method of handling is as follows:—

A wet and dry bulb thermometer is placed in the exhaust air duct and the damper adjusted, so that the volume of air discharged has a predetermined humidity. The supply of steam fed into the heating units is regulated in accordance with the readings of a thermometer located in the uppermost part of the kiln. The readings of a thermometer placed in the bottom allow the determination of difference in top and bottom temperatures.

By that difference it is possible to judge if the material is properly piled in the kiln and what uniformity of drying is being secured.

The operation of such a kiln is evidently a comparatively simple matter and there is no need for skilled and highly qualified operators.

The nature of drying kilns with circulation and reiterated humidification of air is made perfectly clear in Table I. The rapid circulation, owing to which the material being dried is being constantly washed by warm currents of air, is also evident from this table. It should be noted that the constant shifting of air currents on the surface of the drying material constitutes one of the most favourable factors for brisk dehydration.

For example, let the drying temperature be 70°C. the material to be dried being fruit, vegetables, etc., the difference in the top and bottom temperatures 4°C., relative humidity of exhaust air 75 per cent., then the dry air must circulate about 86·5 times through the material and be as many times reheated by the radiators and sent again into the upper part of the kiln. Thus the volume of air circulating in the kiln is 86·5 times greater than the volume of air discharged and, thanks to this fact, an enormous saving in energy consumption is secured.

In Table I. the values for circulation in a drying kiln are given as a function of temperature and humidity of exhaust air, as well as of the difference in top and bottom temperatures. For the calculation of the Table I. the temperature and humidity of fresh air were assumed to be 10°C. and 75 per cent.

The table herewith has been calculated as follows:—

The fresh air contains d_0—grams of moisture per Kg. of dry air.

TABLE I.

Exhaust air.		Difference in top and bottom temperatures.					
Temp.	Humidity.	2°C.	3°C.	4°C.	6°C.	8°C.	10°C.
	25 per cent.	—	—	—	—	—	—
20°	50 ,,	1·5	1·0	—	—	—	—
	75 ,,	6·1	4·0	3·0	2·0	1·5	1·2
	90 ,,	8·8	5·9	4·4	2·9	2·2	1·8
	25 per cent.	—	—	—	—	—	—
	50 ,,	9·9	6·0	4·5	3·0	2·2	1·8
30°	75 ,,	17·2	11·5	8·6	5·7	4·3	3·4
	90 ,,	22·2	14·8	11·1	7·4	5·6	4·4
	25 per cent.	7·0	4·6	3·5	2·3	1·7	1·4
40°	50 ,,	21·4	14·3	10·7	7·2	5·3	4·3
	75 ,,	35·7	23·8	17·9	1·9	8·9	7·1
	90 ,,	44·0	29·4	22·1	14·7	11·0	8·8
	25 per cent.	16·8	11·3	8·4	5·6	4·2	3·4
50°	50 ,,	41·5	27·7	20·8	13·9	10·4	8·3
	75 ,,	65·5	43·6	32·6	21·8	16·3	13·1
	90 ,,	79·3	52·7	39·6	26·4	19·8	15·8
	25 per cent.	32·0	21·3	16·0	10·6	8·0	6·4
60°	50 ,,	71·0	47·4	35·6	23·7	17·8	14·2
	75 ,,	109·2	72·7	54·7	36·5	27·3	21·8
	90 ,,	131·0	87·2	65·3	43·5	32·8	26·2
	25 per cent.	53·0	35·3	26·4	17·6	13·2	10·6
70°	50 ,,	115·0	76·2	57·5	38·3	28·7	23·0
	75 ,,	173·0	115·0	86·5	57·8	43·3	34·7
	90 ,,	207·0	138·0	103·0	69·0	51·8	41·4
	25 per cent.	83·5	55·8	42·0	27·9	21·0	16·7
80°	50 ,,	353·0	118·5	88·6	59·2	44·4	35·4
	75 ,,	262·0	175·0	131·0	87·5	65·5	52·5
	90 ,,	312·0	208·0	156·0	104·0	78·8	62·2
	25 per cent.	126·0	84·5	63·0	42·0	31·6	25·3
90°	50 ,,	361·0	174·0	130·0	87·0	65·2	52·2
	75 ,,	384·0	256·0	192·3	128·5	96·3	76·9
	90 ,,	445·0	297·0	223·0	149·0	111·0	89·0

The exhaust air contains d_2-grams of moisture per Kg. of dry air (determined from table).

Consequently, one Kg. of dry air carries away from the kiln

$$d_2 - d_0 \text{ grams of moisture.}$$

If the air makes only one circulation through the material with a difference in top and bottom temperatures, $\triangle t$ ($= t$ max.—t min.), the increase in its humidity will be:

$\triangle d = A \triangle t$, where A is a coefficient (to be found in special tables), which varies within the range of 0·4 to 0·8. Finally, we obtain the amount of circulation which will be:—

$$n = \frac{d_2 - d_0}{A \triangle t}$$

The following are some results obtained in the practical operation of drying kilns designed and constructed upon the principles of the hydraulic theory.

Fig. 2. Humidity of air in process of drying of light leather.

1. The curve in Fig. 2 shows the decrease in humidity of exhaust air obtained in a test conducted by Messrs. Korol and Pogromsky when drying light sole leather (article published in the "Journal of the Leather Industry," Moscow, 10, 1927, pp. 375-379). "The drying of the light sole leather has been completed in thirty-six hours. Leather was hung up in two superposed tiers. The drying period of the upper tier was four hours less than that of the lower. But in the final stages of drying the moisture content of leather in both tiers tends to become even. The leather is dried down to 7 to 8 per cent. Average drying temperature 42°C."

2. In the same publication Mr. Vensberg makes the following statement with regard to the performance of our drying kilns ("Journal of Leather Industry," II., 1927, pp. 467): "The leather is dried in kilns constructed upon the principles of Prof. Groom-Grjimailo. This system has proved fully satisfactory both as regards economy and control. The principle of reiterated saturation of air, and the fact that it is forced past the leather in downward stream, secures a very uniform rate of drying."

3. Engineer Pavlovitch has also mentioned the kilns in the above journal (II., 1927, pp. 161). He writes: "Drying kilns constructed upon principles of Professor Groom-Grjimailo are very simple in operation."

The above references have been quoted in order to show that a drying kiln that is properly designed and constructed upon the principles of the hydraulic theory can be easily controlled and cannot but produce fully uniform drying, and that without any special effort on the part of the operators.

Uniform drying is produced of its own accord, which is clearly explained as follows.

Two small areas of equal size, one wet and the other dry, on the surface of the leather, are considered. It is obvious that warm dry air will behave in an altogether different manner when striking each of these areas. The stream of air will remove the moisture from the wet area, the air will increase in humidity and will cool and become heavier. The cooled and humidified air will descend and will be replaced by a further quantity of warm dry air. The stream of air striking the dry area will change neither in composition nor temperature and will therefore tend to remain stationary.

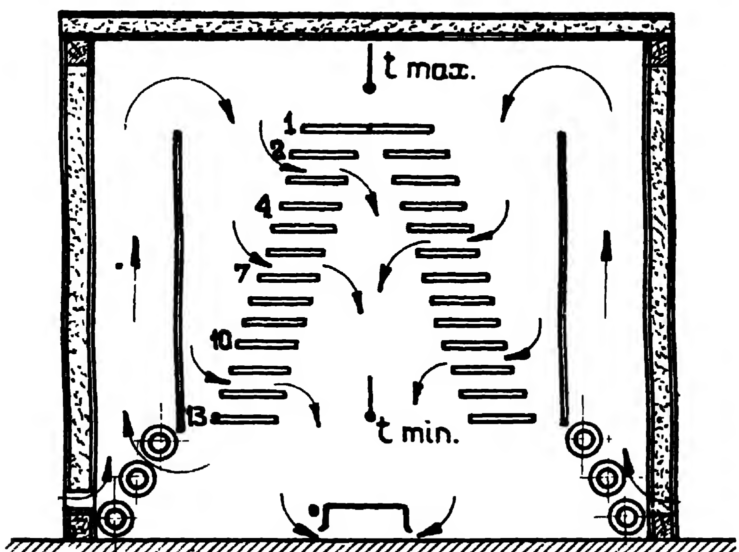

Fig. 3. Experiment dry kiln for dyestuffs.

In this way brisk downward circulation is brought about only by the wet areas of the leather, and at the same time these areas dry up more rapidly.

This is the reason why leather in drying kilns, constructed upon "hydraulic" principles, dries up uniformly in spite of the uneven thickness of the hide.

No instance in which leather was "stewed" is known, and it is quite impossible to effect that process even intentionally.

Natural circulation in rationally designed "hydraulic" kilns affords an ideal solution of the problem of uniform drying. This circulation is effected in conformity with natural physical laws and may be easily subjected to mathematical computation.

Owing to limited space, all the theoretical reasoning and mathematical computations which have been checked in practice must be omitted.

Fifteen drying kilns have been constructed, ten are in course of construction, two more are contemplated.

In the design and construction of drying kilns for dyestuffs great care has been taken. The foregoing description of the kilns indicates that the heating units arranged along the kiln walls produce vertical circulation. Therefore vertical arrangement and open piling are advantageous. Dyestuffs, however, require drying on sheet-iron pans of considerable dimension.

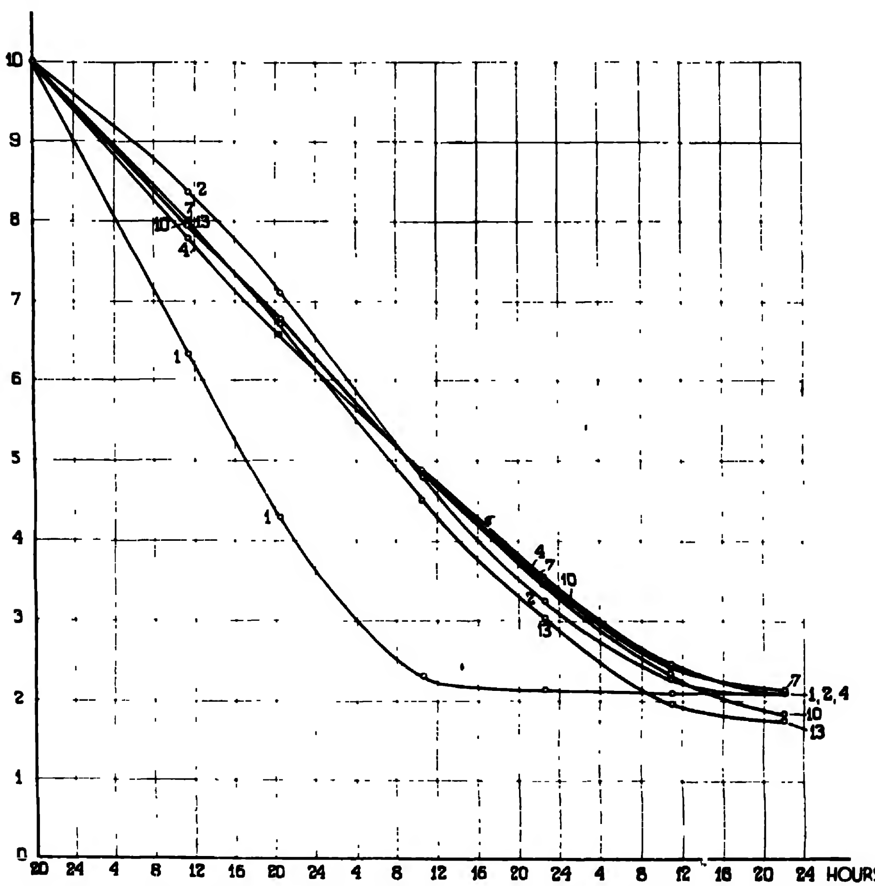

Fig. 4. Decrease in weight of pans with dyestuff placed on different levels.

A method of drying horizontal surfaces was to be found; accordingly that difficulty has been overcome in the design of an experimental kiln, whose operation is shown in Fig. 3. In Fig. 4 the decrease in weights of the control pans, placed on different levels, is shown. The number written on the curve in Fig. 4 corresponds to that of the pan as shown in Fig. 3.

The uniformity of drying conditions is represented by the curves in Fig. 4. The upper pan naturally dries up in much less time than the lower ones do, as the fresh dry air strikes it first. That is both natural and unavoidable in case of the method adopted of arranging material. By the rapid drying of the upper pan such a good humidification of the air is effected that the drying of the lower pans is detained. But when the upper pan becomes dry the drying of the next one goes on with more rapidity, and its moisture content reaches that of the upper pan in a very short time.

The task of timber drying requires a specially careful approach. On that account very much care and attention in the designing of a drying kiln for timber is called for, the technology of the process being not yet sufficiently clear.

Two experimental kilns have been constructed. They have proved so efficient that at the present time the design of a large drying plant for a factory is being worked out. In the kilns designed and constructed upon the principles of the hydraulic theory there is no need for forced circulation produced by means of fans. As the drying period of hardwood beams like those of oak ranges to about a month and more, the cost of power becomes a considerable sum. Greater advantages are, therefore, derived from kilns working without fans.

RÉSUMÉ

En plaçant les appareils de chauffage à l'âtre du séchoir de part et d'autre du monceau des objets à sécher nous produisons une circulation naturelle et ininterrompue de l'air humide qui remplit le séchoir: l'air échauffé par les appareils de chauffage monte et l'air refroidi et humide descend entre les objets à sécher. Grâce à cette circulation continuelle, l'air qui remplit le séchoir s'échauffe constamment auprès des appareils de chauffage, vient en contact avec la surface humide des objets à sécher et devient humide à nouveau. Finalement nous obtenons un séchoir de saturation multiple où il est possible de donner à l'air l'humidité exigée par la technologie du processus. L'air humide est évacué au dehors par un exhausteur placé dans l'âtre du séchoir. L'air frais est introduit à la place de l'air humide évacué par des ouvertures placées près des appareils de chauffage.

La force motrice de la circulation naturelle décrite est la différence entre le poids de l'air chaud du séchoir, chauffé par les appareils de chauffage, et celui de l'air humide refroidi dans le monceau des objets à sécher. Cette force

motrice est une fonction de la différence des températures au plafond et à l'âtre du séchoir. C'est elle qui produit la vitesse de circulation de l'air du séchoir; elle s'amortit en surmontant la résistance de l'air en circulation.

En diminuant la résistance au mouvement de l'air sur tout le trajet de l'air en circulation, nous abaissons la différence des températures en haut et en bas du séchoir et augmentons ainsi la régularité du processus de séchage dans toute la hauteur du séchoir. Le degré de régularité du séchage dans la direction horizontale dépend entièrement de la régularité de la mise en monceau et peut atteindre la perfection. Le caractère du séchage dépend du travai de l'exhausteur. En augmentant ou en diminuant la quantité de l'air évacué, nous augmentons ou diminuons l'humidité de l'air dans le séchoir en obtenant ainsi un séchage plus ou moins lent.

La dépense en air ainsi que le rendement utile du séchoir dépendent entièrement du régime de séchage établi, c'est-à-dire, de la température et de l'humidité de l'air à évacuer, humidité qui peut dépasser 90% sans qu'il y ait danger que la vapeur abîme les objets à sécher. Une telle possibilité fait de nos séchoirs les séchoirs les plus économiques aussi bien au point de vue consommation du combustible qu'au point de vue énergie. Il n'est point nécessaire, dans nos séchoirs, d'avoir recours à la pénétration par la vapeur.

La rapidité du séchage peut être augmentée par l'élévation simultanée de la température de séchage et du degré d'humidité de l'air en circulation La pratique du séchage des peaux, du bois et des couleurs montre que les séchoirs de saturation multiple avec circulation naturelle ont une rapidité de séchage égale à celle des séchoirs de systèmes différents et ne diffèrent de ces derniers que par la régularité du processus.

Le séchoir à bois, essayé à Kieff, fut mis en train successivement avec une circulation naturelle et une circulation forcée. La première s'est montrée comme la plus parfaite au point de vue de la régularité et de la rapidité de séchage. Ainsi donc les séchoirs construits exactement suivant la théorie hydraulique, se montrent comme le type le plus parfait des séchoirs à chambre.

PART II.—FURNACES WITH UNIFORM TOP AND BOTTOM TEMPERATURES DUE TO THE CIRCULATION OF HOT GASES WITHIN THE WORKING CHAMBERS

PROF. W. E. GROOM-GRJIMAILO

The construction of a furnace with uniform top and bottom temperatures is one of the most difficult problems of furnace designing.

The hydraulic theory states that if the space under the arches is made large enough, if the cooling gases are directed downward and the material placed on the hearth is accordingly well heated by a descending stream of flame, if, further, the bottom is well drained, absolutely uniform temperature may be guaranteed throughout any furnace of reasonable size.

Until quite recently it has been quite impossible to reach uniform temperatures on the different levels of such a furnace. The temperature below the arch is always higher than that on the hearth;

and this is, of course, quite natural, since the combustion of furnace gases is completed in the free space below the arch. The hot gases would stay in that space but for the losses of heat through the roof and transfer of heat to the material, which makes them descend. The loss of heat naturally results in a drop of temperature, so that when the gases ultimately reach the bottom their temperature is some 200°C. to 300°C. lower than it was below the arch.

At the same time, in some cases, for example in the calcining of silica or refractories, it is of first-rate necessity to maintain a uniform top and bottom temperature. In these cases the method of delayed combustion is employed, which is easily effected by reducing the excess air to zero.

In a kiln for calcining refractories, quite even top and bottom temperatures may be established if fat coals are employed as fuel, and if a reducing atmosphere within the chamber is maintained. The reaction of combustion slowly proceeds all the while the gases remain in the combustion chamber, and thus the loss of heat in refractories is compensated.

Such work requires a special grade of fuel and very careful attention on the part of the operator. In cases where an oxidising atmosphere within the combustion chamber is to be maintained, the method is of no use. When excess of oxygen is available the combustion is always very brisk and is therefore completed in the space below the arch. The furnace gases descending through the pile of material lose their heat on useful work, and consequently the temperature on the hearth is lower than that below the arch.

In the case of drying kilns designed upon the principles of the hydraulic theory (*cf.* Section I., "On the work of drying kilns. . . ."), altogether uniform drying conditions are easily secured in the horizontal plane and only a small difference in top and bottom temperatures in the vertical plane. This is accomplished by the following means:—

1. Exhaust air is discharged at the bottom.
2. The heating units are arranged along the walls in order to produce a lively circulation in the kiln.

The principle of circulation was originally applied to the construction of furnaces by my son, A. W. Groom-Grjimailo. The four possible lay-outs of such a furnace are shown in Fig. 5. Hot incandescent gases, from the combustion chambers "a_1" and "a_2," located at the bottom, enter the heating chamber and rise up to the arch. There exists a descending current of gases within the material, placed on the hearth (circulation is shown in Fig. 1 by arrows).

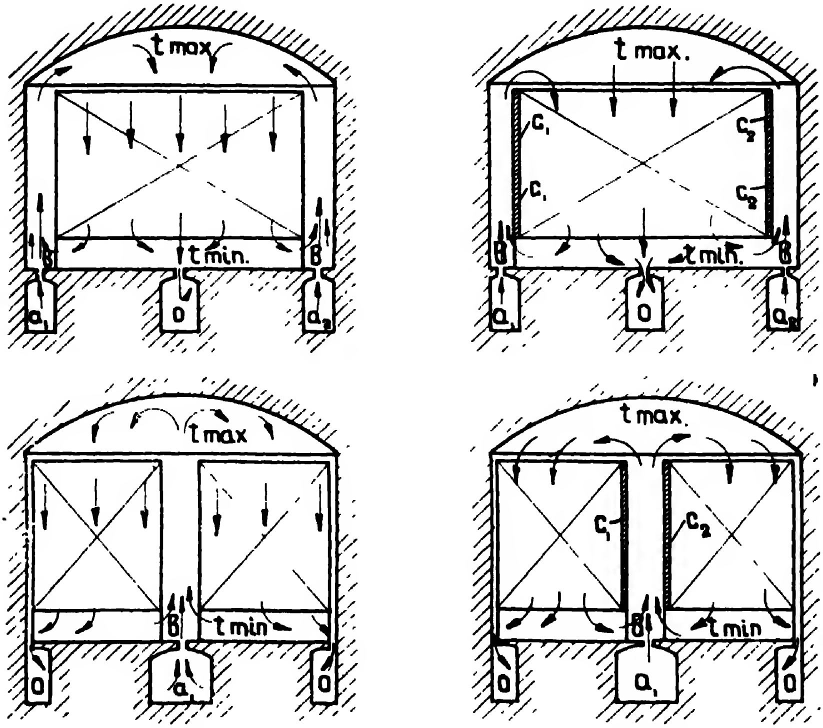

Fig. 5. Four possible schemes of furnace design with internal circulation.

In order to secure a still more lively circulation, screens C_1, C_2 may be arranged in the same way as that generally adopted in drying kilns.

At the present time mathematical computations for this circulation are being undertaken.

The following is a brief outline of some furnaces which have been constructed as a result of these lines of thought:—

1. A furnace for the production of ultramarine.

The oxidising furnace gases were admitted into the combustion chamber below the arch and they descended to the hearth, which was provided with good drainage. The dimensions of that chamber were 7,000×5,000 mm. with a height of 3,000 mm., and a capacity of 2,000 pots. The heating of the material was quite uniform in the horizontal plane, but after twenty-four hours of heating the temperature below the arch was 300°C. higher than that on the hearth. The furnace was recognised as inefficient and the works declined to use it. Since then, the furnace has been remodelled in accordance with the new ideas. The stoker has been located in the heating chamber below the file of pots. Circulation ducts were

provided under the pots and these ducts were given an outlet into the stoker. By proper arrangement of the pots, vertical flues in their pile were formed. Incandescent gases, rising up from the stoker, became mixed with flue gases and the mixture, as a light hot gas, ascended to the arch. The difference in weights of two columns of gases, the ascending hot ones and those cooled and descending within the pile of pots, is the impulse for circulation of gases in the furnace.

The admixture of gases, cooled within the pile of pots, to the incandescent gases, produces a decrease in the temperature below the arch.

The internal circulation of furnace gases produces a rapid change of gases within the pile of the pots. This results in much better heating of the pots and raises the temperature of the gases. In this way the difference in top and bottom temperatures steadily decreases until it reaches some constant figures. The very first lot of ultramarine obtained from the newly remodelled furnace contained nearly 100 per cent. good commercial product.

2. A Fougeront tunnel kiln (Tunnel öfen Keramische Geselchaft in Saaray) has been remodelled upon the same principle of internal circulation at a porcelain and earthenware manufactory near Tver.

The length of the kiln was 65 metres.

According to the statement of Eng. Skwortzoff (see "The Journal of Glass and Ceramic Industry," 1923, Nos. 7 and 8, Moscow), the Fougeront Company, when constructing that tunnel in 1910 had warranted an output of twenty-four tipple-cars per twenty-four hours. The actual output of the tunnel, fed on best firewood fuel, was fifty-five cars in twenty-four hours. The rate of consumption of equivalent fuel with a heating value of 7,000 calories per Kg. was 170 Kg. per car load or 170 Kg. fuel per 250 Kg. of earthenware.

The reconstructed tunnel was made with semi-producer gas firing and with internal circulation of furnace gases. As regards fuel, firewood with 35 per cent. moisture content was used. The output was increased to seventy-two cars in twenty-four hours. The rate of fuel consumption (equivalent fuel) is 88 Kg. per car load, or 88 Kg. per 250 Kg. of earthenware. This means a 30 per cent. increase in the output and a 48 per cent. decrease in fuel consumption. The difference in top and bottom temperatures of the car load is hardly detected by a thermocouple.

Such a low difference in top and bottom temperatures greatly assists the production of high quality wares. It is quite obvious that various special devices and cunning contrivances used in

numerous designs of tunnel kilns in order to obtain a uniform rate of heating are altogether superfluous. The hydraulic theory has solved the problem in a very simple way. The CO_2 content in furnace gases varies from 14·5 per cent. to 17 per cent., which may be considered quite satisfactory for a tunnel kiln.

3. The thermal treatment of commercial articles of considerable length is a matter of great difficulty. The hydraulic theory gives a most simple and clear solution to the problem. A furnace, constructed on these lines, was placed in service and best results were obtained, the difference in its top and bottom temperatures being so small that it could hardly be detected at all by pyrometers.

Such a complete uniformity of heating is due to two factors. (*a*) The combustion chamber has a ring shape located along the periphery of the whole furnace—thus the heat losses, due to radiation, convection, etc., are obviated. (*b*) The incandescent gases enter the heating chamber at the bottom through narrow ports. They assist the upward ascension of furnace gases, which have cooled through contact with the cold piece to be heated. A continuous intense circulation is produced in that way. The hot gases ascend along the walls and the cooled gases descend around the cold long piece. This circulation cuts down the difference in top and bottom temperatures to a few degrees centigrade only. The greater the diameter of the furnace, the less is that difference.

4. Furnaces for annealing wire or malleable iron castings in pots are usually constructed with bottom firing and with outlet flues located in the top. It is quite obvious that the heating of pots in furnaces of such faulty construction is uneven. In a number of these furnaces with top firing and bottom discharge the pots were heated uniformly from all sides, but a low difference in the top and bottom temperatures could not be established.

The application of the method of delayed combustion exerted only a slight beneficial influence.

The problem was solved only by building a furnace with internal circulation.

Incandescent gases from the combustion chamber enter the heating chamber at the bottom. They assist the ascension of cooled furnace gases to the top by mixing with the latter and heating them. The hot gases filling the upper part of the heating chamber, when coming into contact with the cold pot, flow down along the pot walls and are partly discharged into the flue, partly mixed up with the incandescent gases of the combustion chamber. Thus an effective

internal circulation is set up. Some structural units, however, have to be altered for the purpose.

The heating chambers of furnaces with internal circulation should be made of larger size than is usual.

This principle has in no case failed to secure the best results. On this account the principle of circulation is being introduced into all new designs, if an improved transmission of heat and uniform heating with a low difference in top and bottom temperatures are desired.

It is hoped to present a description of a whole set of furnace designs based upon the principle of circulation to the next conference.

RÉSUMÉ

Les fours à chambre chargés régulièrement des objets à recuire, régulièrement alimentés par le débuché des flammes, avec une juste construction de l'âtre et avec un contre-feu, peuvent assurer une cuite égale dans la direction horizontale. Jusqu'à présent on n'a pas réussi à atteindre une température égale dans la direction verticale.

Les premières expériences en construction de fours à chambre à reverbère avec circulation des flammes dans l'espace utile, s'élevant des débuchés en haut et puis descendant au milieux des objets à cuire, pareille à la circulation de l'air dans les séchoirs, ont donné d'excellents résultats. On a déjà réussi à atteindre une température égale, en limites de quelques degrés, en haut et en bas dans un four de six mètres de hauteur. Travaillant dans cett edirection, nous réussirons, sans doute, à construire des fours d'une hauteur quelconque avec une température égale dans toute la hauteur du four. C'est un nouveau type de four auquel appartient un bel avenir.

PART III.—THE LOSS OF HEAT TO A FREE STREAM OF GASES

PROF. M. KIRPITCHEFF

The hydraulic theory considers the movement of the flame, as the movement of a light fluid inside of a heavy one.

For treating correctly the problems of the flame's work in furnaces and that of the hot air in drying plants from the hydraulic point of view we need to know:

1. The mechanism of the movement of hot gases;
2. The mechanism of heat transfer by convection;
3. The dependence of the numerical value of the heat transfer upon the size, situation, shape and nature of the surface.

Such knowledge supplies us with a proper basis for calculating and designing thermotechnical constructions. Thus we meet with the necessity to study in an experimental way the character of the

movement of convection currents and their influence on coefficient of heat transfer in different practical cases.

The report, which is published below, represents the first investigations of the problem carried out by the State Physical Technical Laboratory in Leningrad. In spite of their apparently theoretical character, they are exceedingly interesting in relation to practical problems.

The experiments are not numerous enough for complete calculations of the heat transfer in detail, but the importance of this work consists in the research method developed by the Laboratory.

Heating apparatus frequently work with a free stream of gases. The movement of the gases in such apparatus takes place owing to the change of density produced by the contact with the working surface of the given apparatus. Whilst in the case of the forced stream the law concerning the dependance of the heat loss on the velocity of the gas can be easily formulated, the case of the free stream is much more complicated. The movement of the gases here is due to the exchange of heat and the movement produced influences the value of the heat exchanged. Thus the laws of the heat exchange between a solid body and a freely moving gas are practically unknown, and even the nature of the gas movement has not been studied.

It is of a great practical interest to know the law of the transfer of heat from a vertical pipe. This question solved, we could be able, for instance, to make the thermal calculation of the boiler proposed by Prof. Groom-Grjimailo, described in the *Stahl und Eisen*, 1925. It is also of importance to examine the conditions of work of metallurgical furnaces, and to investigate the transfer of heat from the horizontal and vertical flat walls. Both those questions are studied at the State Physical Technical Laboratory, Leningrad, and the first series of experiments is already finished. The experiments were guided by M. V. Kirpitcheff and A. A Gukhman, and carried out by M. A. Mikheieff, L. S Eigenson and V. S. Joukovsky.

The transfer of heat from vertical pipes of different diameters and lengths has been investigated. Two pipes had a diameter of 5·5 cm. and lengths of 3 m. and 6 m. The third and the fourth had diameters of 2·8 cm. and lengths of 0·9 m. and 1·6 m.

The longest pipes were studied in a large room, a part of which was separated by a wall, the upper end of which remained half metre below the ceiling (Fig. 6).

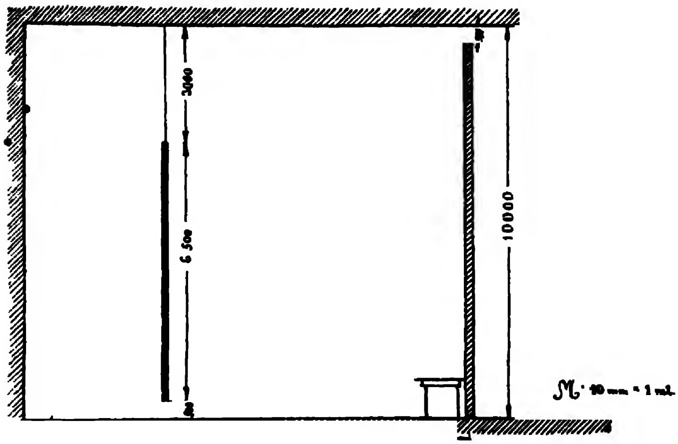

Fig. 6. The experimental arrangement for studying vertical pipes.

The pipes were uniformly heated by electricity, using a ribbon wound spirally on the pipe. This arrangement reduced considerably the heat exchange in the metal along the pipe and facilitated the establishment of the distribution of the temperature corresponding to the transfer of heat on different places of the pipe. The average temperature in different zones of the pipe was measured by bolometers. Moreover, the temperature of certain points of the pipe was measured by thermo elements.

Fig. 7 The picture of the motion of gases near the heated vertical pipe. A—the lower part. B—the upper part.

It is evident that an examination of the laws governing the heat transfer in a free stream can only be fruitful if a parallel study of pictures of the flow of gases is made. For this purpose we used the point-light method of Dvorzak-Boys.

Fig. 7 represents the pictures of the motion of the air heated by a pipe. Along its lower part the air moves laminarly. Further, when the critical velocity is reached, curls, following one another in the stream of the warm air, can be observed. These curls are in complete agreement with the Mollock prediction ("Reports and Memoranda of Committee for Aeronautics," 1, 1916-17, p. 13).

This type of motion exists on a certain length of the stream, after which the curls are destroyed and a turbulent motion of hot air takes place, the individual sections of which move irregularly in sinuous lines, mixing with the cold air surrounding the pipe.

In agreement with the three regions of different types of motion observed, the change of temperature along the pipe is also different.

While the laminar motion still exists the temperature of the pipe gradually increases. Then in the region of curls, the increase of the temperature ceases and with the appearance of the turbulent motion the temperature decreases considerably at the beginning, then it remains nearly constant with a very slight tendency to drop further. Fig. 8 gives the distribution of temperature at different heights for the pipes of different sizes and suggests the

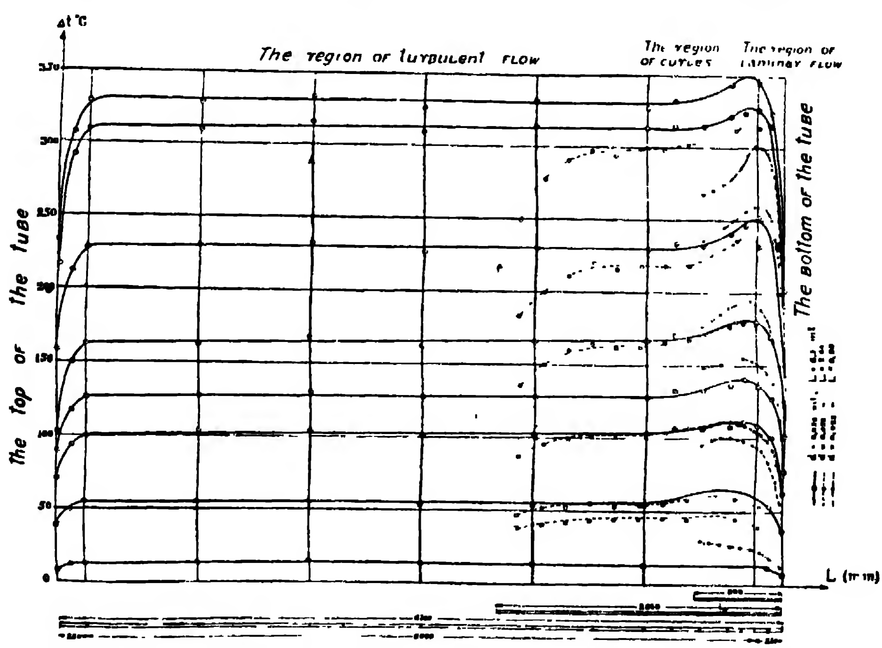

Fig. 8. The temperature distribution along the heated vertical pipe.

following unexpected conclusions: that the length of the zones of laminar and curl-motions is almost independent of the diameter of the pipe. The zones of turbulent motion are also equal, a difference existing only on the end portions where the cooling through the ends of the pipes has its effect. As the temperature excess, ΔT, rises, the length of the first two zones, as would be expected, decreases, because the velocity of the air increases and its viscosity decreases. The coefficient of the heat loss in different portions of

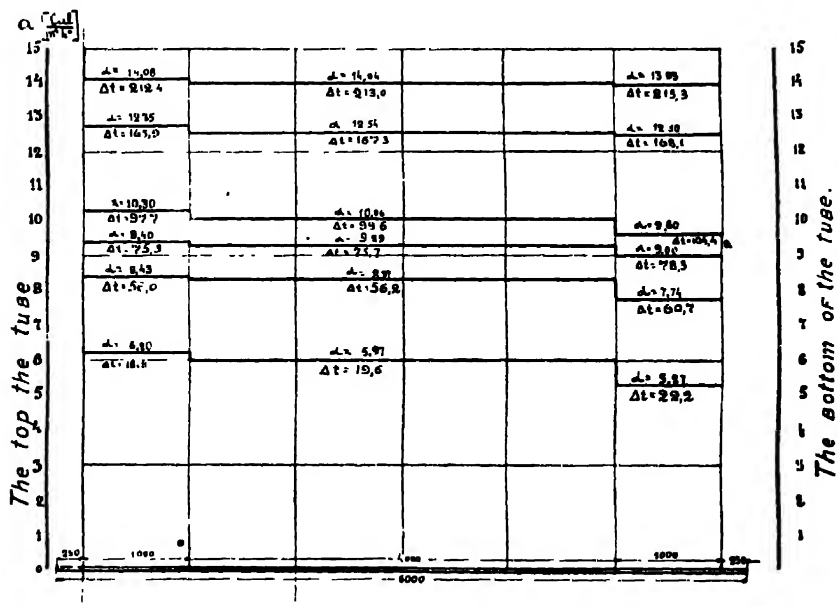

Fig. 9. The coefficient of heat loss from different zones of a vertical pipe.

the pipe, as given by Fig. 9, is completely in agreement with the picture of the moving air and the observed distributions of temperature along the tube.

The quantity of the heat transferred, computed from the experimental results, contains the heat transferred not only by contact, but also by radiation. For the purpose of determining coefficient of radiation (a_R) the smallest of the pipes, 0·9 m. long, was studied in a vacuum at the pressure equal to 10^{-5} mm. of mercury. This investigation permitted the separation of the radiant heat and the computation of the coefficient of the heat transfer by convection.

It is represented by Fig. 10 as a function of the excess of temperature. A curve can be drawn through all the observed points, which can be expressed by $a_c = 1{,}9 \cdot \Delta T^{0{,}29}$.

The fact that observed results can be represented by an identical formula for pipes of different sizes, makes one draw the conclusion

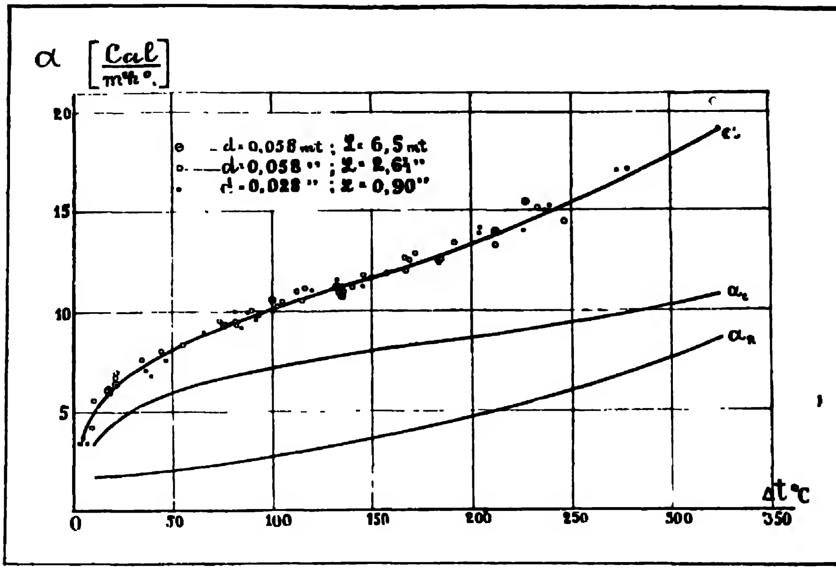

Fig. 10. The coefficient of heat loss from a vertical pipe at different temperature excess.

that general laws could be found on the basis of the theory of similitude.

This theory states that similar processes have equal complexes of value

$$Nu = \frac{\alpha \cdot d}{\lambda_m} \quad \text{and} \quad Gr = \frac{d^3}{B^2_g} \cdot \frac{\Delta T}{T^3_m \; M^2_m} \cdot p^2,$$

where λ_m and M_m is the mean heat conductivity and the mean viscosity, B - the gas constant, T_m - the mean temperature and p – the pressure of the medium. But the existence of similitude can be proved by experiment only. As the experiment suggests that $Nu = f\,(Gr)$, the value Gr must be considered as the criterion of the similitude. For the coefficient of the heat loss to be independent of the size of the pipe Nu must be proportional to $\sqrt[3]{Gr}$.

Plotting the experimental results of Nu and Gr (Fig. 11) we obtain in logarithmic anomorphosa a straight line in complete agreement with the theory: $Nu = 0{\cdot}14\ Gr^{0{,}334}$.

A further task consisted in the studying of the influence of the slope of the pipe on the transfer of heat. The examination of the motion of gases around a heated pipe, showed (Fig. 12) that in the case of pipes of a small diameter the stream flowing around remains laminar until a certain height, where it becomes turbulent; this transition occurs suddenly.

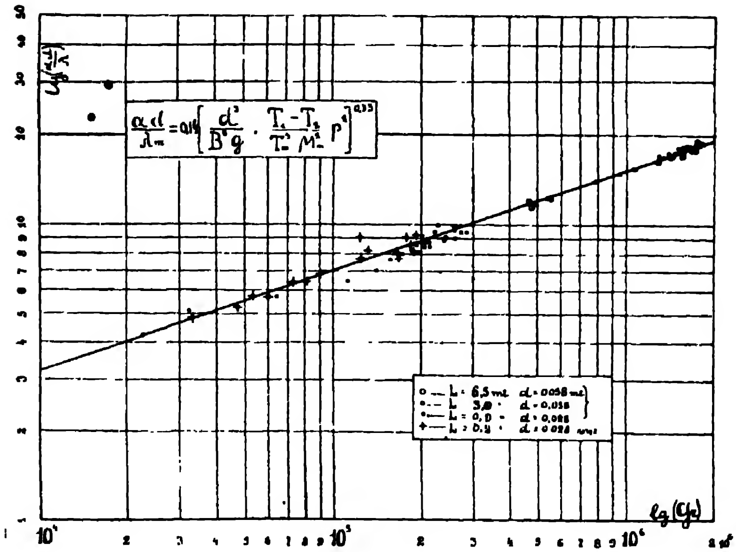

Fig. 11. The examination of the validity of the law of similitude for the case of a free stream of gases.

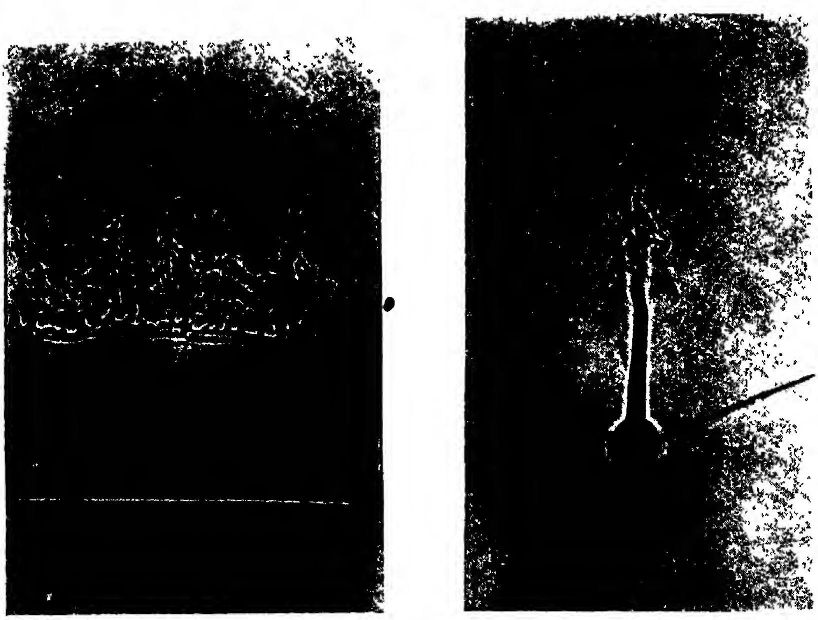

Fig. 12. The picture of the motion of gases around a heated horizontal pipe of small diameter.

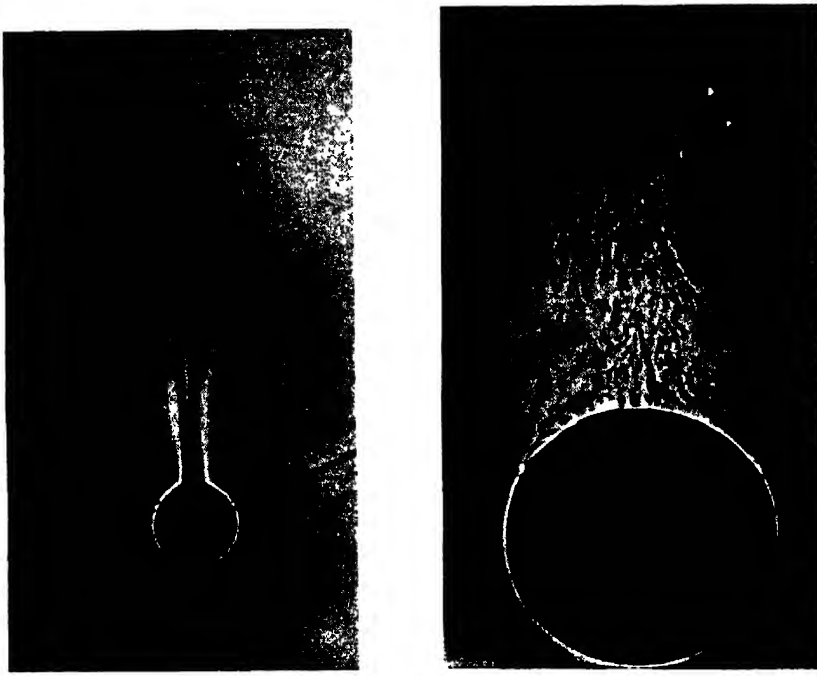

Fig. 13. The picture of the motion of gases around pipes of greater diameters.

As the diameter of the pipe increases, the zone of the laminar flow gradually decreases and at last disappears completely (Fig. 13). This fact suggests the conclusion that at a certain diameter in the case of horizontal pipes, the transfer of heat may cease to be independent of its size, which, as is well known, is proved by the experimental data, for instance, by the investigation of Griffiths and Jakeman.

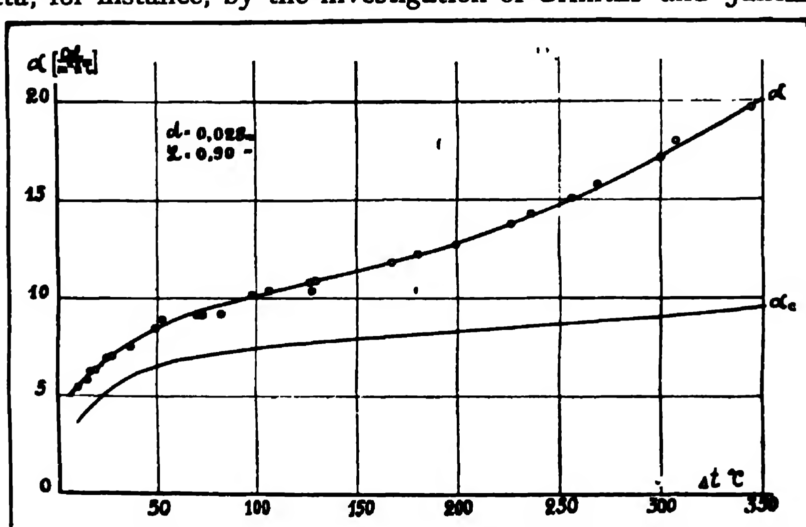

Fig. 14. The coefficient of heat loss from the horizontal pipe.

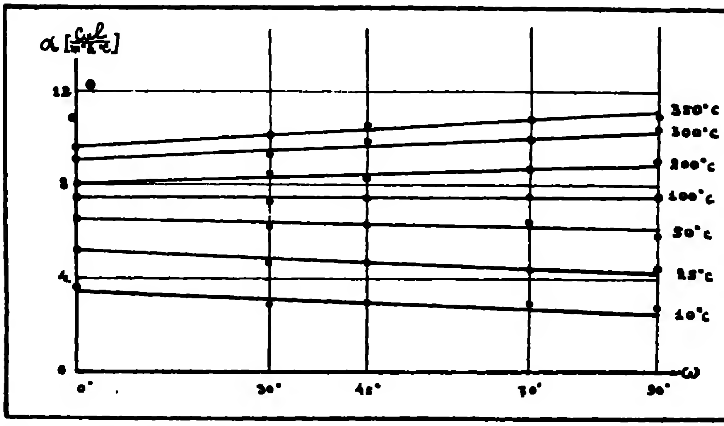

Fig. 15. The coefficient of heat loss as a function of the slope of the pipe.

The experimental data for the horizontal pipe of 2·8 cm. diameter is given by Fig. 14. The coefficient of heat loss plotted against the slope of pipes is represented on Fig. 15. It may be noted that the data measured on a horizontal pipe is lying nearly on the curve obtained for the vertical pipes (Fig. 11).

At the present moment the laboratory is investigating a bunch of pipes. This investigation will supply us with a complete set of data required for the heat calculation of the Groom-Grjimailo boiler and other heating apparatus, based on the free flow of gases. Another case, which is of great practical importance, deals with the transfer of heat from flat walls. The theoretical consideration and preliminary experiments have shown that the character of the movement of the gases and the heat exchange are, in this case, essentially connected with the size of the object. At the present moment experiments have been carried out with a separate flat plate of the size 0·7×0·7 m. freely hung up in the air. Vertical and horizontal plates were studied, the latter facing both upwards and downwards. Ir accordance with the general point of view of the laboratory, an investigation of the air motion in the neighbourhood of the heated plate was carried out. In general this motion was found to be identical with that of the flow around the pipes. The vertical plates showed all the three zones of the laminar, curl and turbulent flow (Fig. 16). In agreement with this fact the distribution of temperature (Fig. 17) was similar to that of the vertical pipes.

A horizontal pipe showed an interesting effect of warm streams flowing on the surface from its edges to the centre. This tendency of warm flows to be pressed against the surface becomes much more evident when it is slightly inclined. The same effect was observed

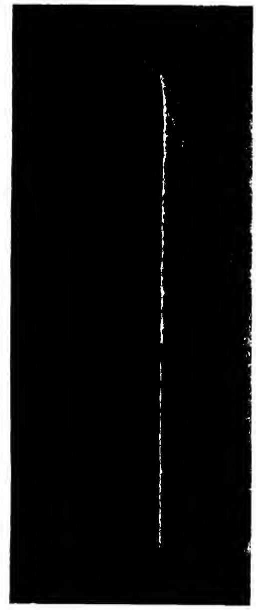

Fig. 16. The picture of the gas motion around the heated vertical plate.

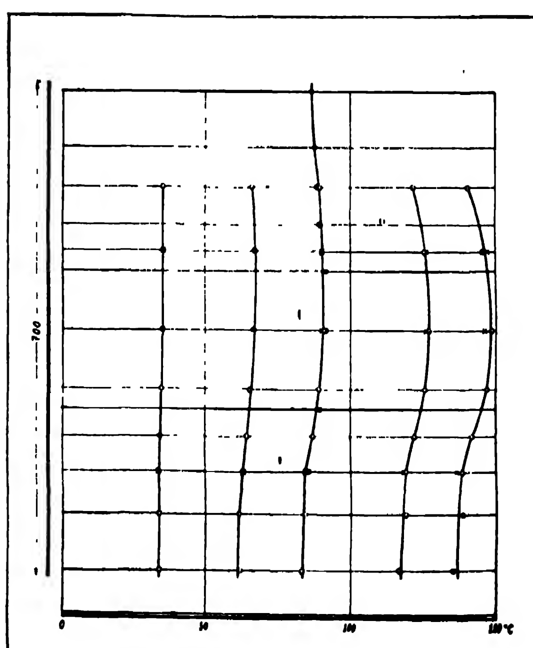

Fig. 17. The temperature distribution along the height of vertical heated plate.

Fig. 18. The picture of the motion of gases around the inclined heated pipes.

in the case of inclined pipes (Fig. 18), horizontal pipes of big diameter (Fig. 13) and ridged pipes (Fig. 19).

This can be explained by the fact that a smooth surface hinders the gas streams less than the surrounding cold air. This phenomenon was pointed out by N. A. Slessaref in 1914.

Fig. 19. The picture of the motion of gases around a horizontal Foster-pipe.

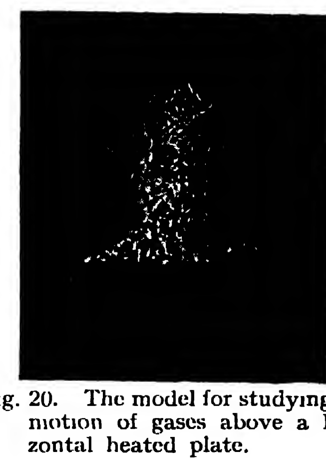

Fig. 20. The model for studying the motion of gases above a horizontal heated plate.

Simultaneously with the direct investigation of the motion of air, the laboratory studied the same effect on models. Fig. 20 gives the picture taken by the optical method, representing the motion of water above a hot plate.

With plates of a large size the motion is different Streams of hot air rising above the plate produce a kind of hedge hindering

the cold air from the sides from replacing them. For this reason the heavier cold air breaks through from above, tending to reach the centre of the plate, and produces an effect analogous to the phenomena of "air-pits" observed in Sahara. This effect was presupposed by Prof. Groom-Grjimailo.

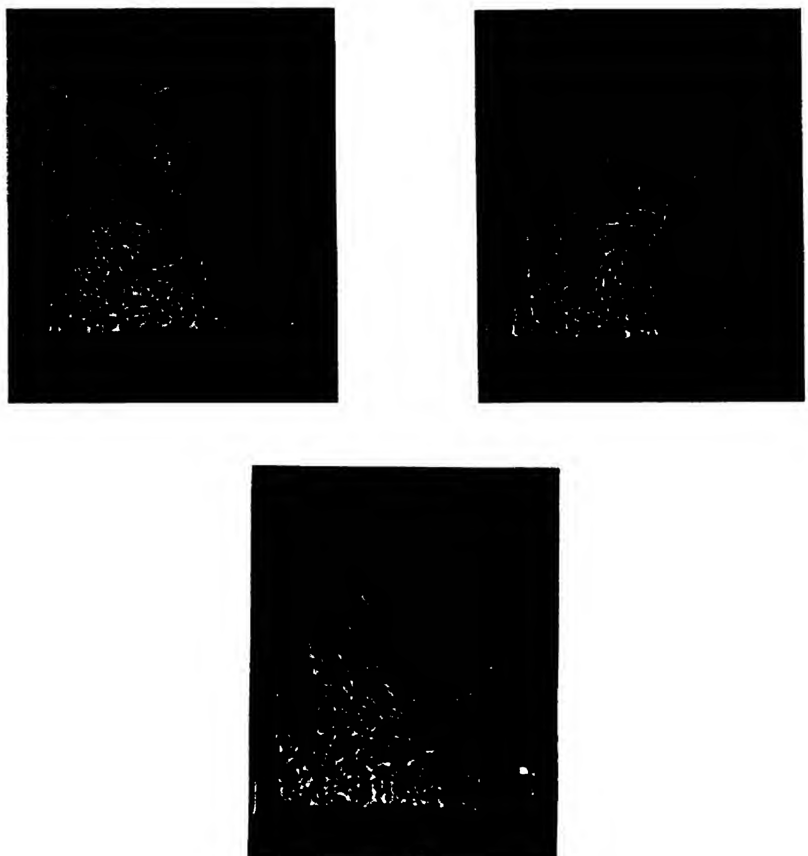

Fig. 21. The model of the "Sahara-effect."

The same "Sahara effect" can also be obtained on smaller plates if we prevent the flow of cold air from the sides. Fig. 21 represents some photo-pictures of such an effect obtained on a model. They were photographed within 10 seconds of each other.

The "Sahara effect" was studied more in detail on a plate 0·7 × 0·7 m. in size. The Fig. 22 represents the motion of the hot air in the central part. When this effect is observed under natural conditions, streams of air falling down and air-spouts slowly moving above the central part of the plate can be observed.

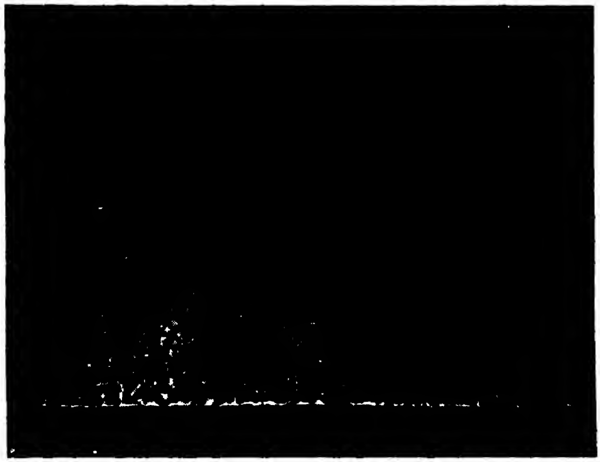

Fig. 22. The picture of the "Sahara-effect" above a horizontal heated plate.

The motion of hot air is quite different in the case of a horizontal plate looking earthwards. In agreement with the hydraulic theory, the lower layers of the cold air take no part in the process. This

Fig. 23. The model demonstrating the stationary layer under a horizontal heated plate.

can be easily seen on Fig. 23, where the lower layers of the darkly coloured water remain immobile. The hot layer under the plate is pushed out because of the difference of densities between the hot water and the cold water surrounding it. This effect can be clearly demonstrated on the model with the coloured water, if on both sides of the plate we place a few bits of a colouring substance. An immobile dark trace remains. The photographs given by Fig. 24

Fig. 24. The model of the convection currents under a horizontal heated plate.

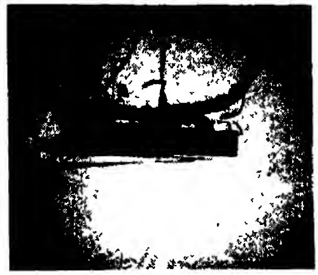

Fig. 25. The path of the cold streams under the plates.

were taken one after another at intervals of 10 seconds. They demonstrate the layers of the cold air coming from the edges of the plate, whilst the hot layer under the plate moves from the centre to the edges of the plate. Fig. 25 represents the details of the path of cold streams. Experiments carried out with the plate 0·7×0·7 m. in size showed exactly the same picture of movement of the air.

In agreement with the different mechanisms of the motion of air the heat loss in each of the three observed cases is different. It is greater for the horizontal plate looking upward (Fig. 26) and it is less for the vertical one These results are in agreement with the experiments of Nusselt. The same result is obtained by excluding the effect of the radiant heat (Fig 27). The least coefficient of heat loss is found for a plate looking earthward The surroundings

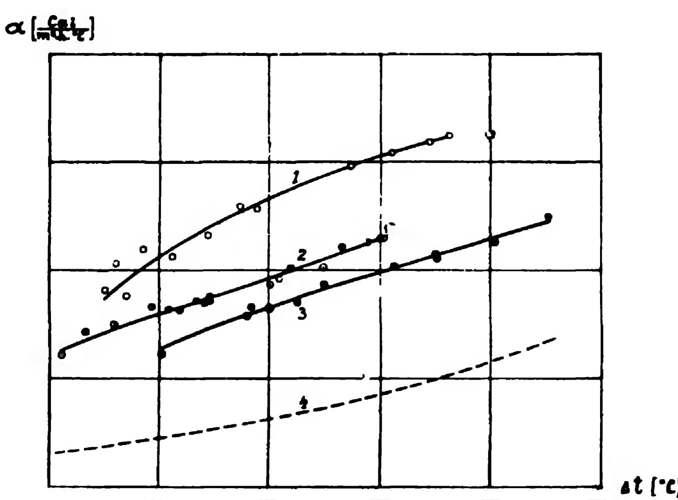

Fig. 26. The coefficient of the heat loss of
(1) The horizontal plate looking upward.
(2) The vertical plate.
(3) The horizontal plate looking earthward, and the coefficient of emissivity (4)

Fig. 27. The coefficient of the convection heat loss from
(1) The horizontal plate looking upward (° ° °—the same, Nussalt's expts.).
(2) The vertical plate (· · ·—the same, Nussalts.).
(3) The horizontal plate looking earthward.

of the plate looking earthwards with small vertical walls considerably decreases the convection heat loss. This case reproduces artificially the conditions corresponding to the loss of heat by a ceiling, because it excludes the supply of cold air from the sides.

As the whole effect essentially depends upon the sizes of the plate referred to, no general conclusions can be drawn from the results obtained, which represent only the first steps in the investigation of the problem. A plate of 3×3 m. is at the moment under the invesuigation.

In conclusion, numerical data are given for the coefficient of heat loss for the cases investigated so far.

PIPES

Vertical $\alpha_t = 1{\cdot}9\ T^{0.29}$

Slope angle with the horizontal

70° .. $\alpha_t = 2{\cdot}1\ \Delta\ T^{0.2}$

45° .. $\alpha_t = 2{\cdot}2\ \Delta\ T^{0.25}$

30° .. $\alpha_t = 2{\cdot}4\ \Delta\ T^{0.24}$

Horizontal .. $\alpha_t = 2{\cdot}5\ \Delta\ T^{0.3}$

The intervals of temperature: 10° — 350°C.

The intervals of diameters and lengths:

From length = 0·8 m. and diam. = 2·9 cm.
To length = 7·0 m. and diam. = 5·8 cm.

Plate

Vertical

The interval of temperature	15° — 85°C.	$a_c = 3{\cdot}45 \triangle T^{0.13}$
,, ,, ,,	85° — 150°C.	$a_c = 2{\cdot}1 \triangle T^{0.24}$
Horizontal looking upward		
	20° — 90°C.	$a_c = 2{\cdot}95 \triangle T^{0.27}$
	90° — 150°C.	$a_c = 4{\cdot}2 \triangle T^{0.19}$
Horizontal, looking earthward		
	50° — 140°C.	$a_c = 1{\cdot}5 \triangle T^{0.27}$
	140° — 200°C.	$a_c = 5{\cdot}6 =$ Const.'

Size of the plate—$0{\cdot}7 \times 0{\cdot}7$ m.

RÉSUMÉ

La théorie hydraulique considère le mouvement de la flamme comme mouvement d'un fluide léger dans un fluide lourd.

Pour traiter correctement les problèmes de l'action de la flamme à l'intérieur des fours, et de l'air chaud à l'intérieur des séchoirs au point de vue hydraulique, il nous faut connaître:

(1) le mécanisme du mouvement de gaz chauds
(2) le mécanisme de la transmission de chaleur par convection
(3) la dépendance de la valeur numérique de la transmission de chaleur de la grandeur, de la situation, de la forme et de la nature de la surface.

Ainsi, nous recevons les données nécessaires au calcul et au dessin de constructions thermotechniques S'en suit la nécessité d'étudier de façon expérimentale le caractère du mouvement des courants de convection ainsi que leur influence sur les coefficients de la transmission de chaleur dans les différents cas.

Le présent mémoire expose les premières expériences faites par les laboratoires d'Etat à Léningrade. Malgré leur air plutôt théorique elles n'en sont pas moins intéressantes à la solution de problèmes pratiques. Les expériences ne sont pas encore assez nombreuses pour permettre des calculs complets et détaillés sur la transmission de la chaleur; leur importance consiste plutôt dans les méthodes de recherches qui ont été adoptées.

INDUSTRIAL GAS IN THE UNITED STATES—GROWTH AND TRENDS

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INTRODUCTION

This paper discusses the growth and trend of industrial gas utilisation in the United States. Data and statistics are given showing by classes how the sale of natural, manufactured, coke-oven and blast-furnace gas has varied by years for the period from 1919 to 1927. The development of modern heat treating as a step in a continuous process is emphasised by photographs and data showing some of the more modern heating applications in the steel plant, heat treating of ferrous and non-ferrous metals, the preparation of foodstuffs, the manufacture of

ceramic articles, and any number of miscellaneous processes. Well-established applications are used in this presentation rather than applications which occur infrequently. The advantages which brought about the increase in the use of gaseous fuels are considered in the conclusion of the paper.

PART 1

ECONOMICS OF INDUSTRIAL FUEL UTILISATION

HENRY O. LOBELL

Gas as a fuel plays an important part in the United States industrial fuel set-up. At the present time the amount of gas used as industrial fuel annually, including manufactured, coke-oven, natural, and producer gases, has a value in the neighbourhood of $650,000,000, representing approximately one-fourth of the total value of all fuel used industrially in the United States per year.

If we look toward the future and study the trend of industry, the use of gas as an industrial fuel is of still greater importance because the demand and need for gaseous fuel is rapidly increasing. During the past twenty years the sales of gas in the manufactured gas industry for industrial purposes has increased thirty-fold, until to-day approximately 25 per cent. of all gas sold by public utilities is used for industrial purposes. .

Industry the world over is ever changing in its march of progress. As we move along we see a gradual but consistently greater degree of co-ordination between the industrialist and the scientist. The demand for higher quality standards of production is forcing industry to utilise the skill of the chemist, physicist, and engineer. Rigid and exact specifications are determined for a product in the laboratory, and it is the problem of industry to manufacture to such specifications on a large commercial scale at the lowest possible cost.

In many cases the methods of furnace operation in use to-day are entirely unsuited to make a product such as the laboratory prescribed, and in other cases the cost of production on a basis of present practice is entirely out of line. In other words, the high standards of production at nominal cost demand newer and better methods of industrial heating and industrial furnace design.

In projecting the work of the scientist to large scale production

the first problem involved is that of having a method of processing which shall turn out a product meeting the specifications determined by the laboratory. This means control of those factors affecting the quality of the product. In many cases when we attempt to utilise present furnace construction and operation, we are unable to obtain the proper degree of control because the furnace is entirely hand-operated and hand-controlled, and is subject to all the variables developing from the use of hand labour or the human element.

From the standpoint of production cost the labour element also seems to be the critical point. In general, the important factors affecting production costs can be itemised as investment charges, spoilage, labour, fuel costs and maintenance. In the United States, where capital is plentiful and can be obtained at a nominal price, and where the cost of fuel is also relatively low—these two items are not of prime importance. The other three factors of spoilage, labour, and maintenance, are usually the important factors of cost, due again perhaps to the high cost of labour in the United States with relationship to the cost of capital and fuel. An analysis of these three items actually brings up the same problem of the human element, because spoilage and maintenance are largely due to the inability of the average workman to have sufficient and definite control over the heating operation to reduce spoilage and maintenance as low as is possible where a greater degree of control is obtained by some other means.

The trend of industry is to make a better product at the lowest possible cost. Since the part that labour plays in the industrial process has often prevented the manufacture of a product with the necessary qualifications, as prescribed by the laboratory, and since the element of labour is usually the most predominating factor in regard to cost, the trend of furnace development in the United States has been in the direction of eliminating labour, eliminating the human element, and applying those methods in furnace operation which will provide both a more exact and a greater degree of control. Furnaces are being made automatic in operation, resulting in the same degree of precision, accuracy, and perfection, as is obtained in the average type of mechanical equipment. Besides the application of mechanics, other features of control, such as instruments for the regulation of furnace temperatures, pressure, and atmosphere, have been developed.

which will control these factors with a far greater degree of accuracy than has been possible by the keen skill of the intelligent workman For example, by means of mechanical devices we are able to time the processing of any particular material to a fraction of a second, and through the use of the proper type of temperature control equipment we are able to regulate furnace temperatures so that the temperature of any particular point over the entire furnace varies no more than one or two degrees. In many cases such control is absolutely necessary, and at the same time is physically impossible unless the human element is largely eliminated.

In the United States great strides have been made in this direction, largely due to the fact that we have been favoured with a plentiful supply of money at low cost, and also because of the fact that the high relative cost of labour to fuel and capital has in many cases necessitated a change. In the second general section of this paper newer methods of furnace design and operation for specific industries will be discussed in detail.

In those processes where either the quality standards of production or the cost of manufacture indicate the advisability of using a furnace of the newer design, involving automatic operation and various types of control equipment, we are always confronted with a great obstacle—the selection of a satisfactory fuel. In other words, assuming that we have a furnace which will turn out a product in the exact time and control furnace temperatures and atmosphere accurately, have we a fuel available which can be burned in a manner so that we can effectively use this equipment? Obviously, if we have a fuel which is always producing different conditions of temperature and atmosphere in a furnace it is impossible effectively to use accurate control equipment, and the automatic arrangements of the furnace will fail to turn out a satisfactory product because a definite time for production assumes definite conditions in the furnace. All of this means that we must have a fuel which we can control, so that through the use of automatic controls we can maintain our furnace at the proper temperature and pressure and under the proper atmospheric conditions, so that, in turn, the automatic equipment turning out the product in a definite time will give us, on a commercial scale, material comparable to that produced in the laboratory.

Our great problem in the application of the newer methods of furnace design involves the availability of a fuel hav the proper specifications and characteristics of combustion. requirements of a suitable industrial fuel fall under four divisions

1. *Definite Composition.* It is obvious that any fuel which shall produce definite characteristics of combustion must be constant in its composition. If the fuel varies in its original make up it will necessarily vary in the way it burns, and will produce variable conditions in the furnace, so that such a fuel would be unsatisfactory in so far as its effective application to an automatically-operated furnace was concerned.

2 *Clean- Free from Impurities* Not only must the general composition of the fuel be constant, but the fuel must be clean in so far as impurities are concerned. Very often minute quantities of various impurities, such as tar or sulphur, will have a serious effect on the quality of the product produced, so that the spoilage of material is prohibitive

3 *Flame Temperature* A fuel, to be applicable to the general scheme of proper furnace design must have such flexibility of combustion that, under varying conditions of application, it can develop a wide range of temperatures. That is, the fuel must have the ability of developing a high flame temperature where necessary The need of this characteristic is obvious, as any fuel which will not develop a flame temperature as high as the temperature at which many of our industrial processes are carried on will be ineffective in doing useful work in the furnace.

4. *Flame Propagation.* The flame propagation characteristics of the fuel must also have a wide range. That is, the maximum rate at which the fuel burns must be high, in order that the application of the fuel may be flexible in so far as obtaining the proper furnace effects in connection with localisation of heat at those points where temperature and quantity of heat liberated are desired

The trend of industrial heating in the United States is in the direction of mechanically-operated furnaces equipped with precision instruments to control the important factors of the process. This general type of operation requires a fuel of certain characteristics, and it may be of interest to survey the various fuels available to-day and consider to what extent they fulfil these

requirements. The first general group are those classified as solid fuels.

Coal in lump form is an inexpensive fuel available in large quantities. Its composition, however, varies, and it contains varying amounts of impurities. Its combustion is complex, involving, prior to combustion, such necessary steps as carbonisation of the coal, vaporisation, decomposition and gasification of the volatile products, and gasification of the carbon residue formed. The problem of ash is also a serious one. In general, under conditions of hand firing, lump coal is almost impossible to control from the standpoint of temperature and atmospheric conditions in the furnace, and, therefore, this fuel can only be considered satisfactory in those operations where the only requirement is heat quantity regardless of the conditions under which the heat is produced.

The application of mechanics to the actual burning of coal, namely, the stoker, has resulted in considerable improvement in the cost of firing coal and the general control of combustion. The extent, however, to which we fulfil the necessary requirements of the proper fuel by the use of lump coal is almost nil, due to the varying composition and combustion characteristics of coal and the complex nature of the overall combustion process necessary with this fuel.

In general, the problems involved in the burning of lump coke are similar to those of lump coal, with the exception that the combustion of the coke is cleaner, owing to the fact that the complexities of burning the volatile matter of the coal are not present.

Pulverised coal is an important step in the right direction. The combustion of the fuel is automatically or mechanically controlled, the temperatures that can be developed are high, the flame propagation of the fuel is rapid, and the ability to localise heat is much greater than the control obtained when using lump fuel. Powdered coal, however, due to the fact that its original composition varies, that it contains impurities and that the ash problem is serious, has been of greater help from the standpoint of lowering the cost of fuel utilisation than of allowing us to consider the use of solid fuels in the light of a sufficiently refined heating medium for the fully automatic industrial heating operation of to-day.

Fuel oil and tar oil are important as liquid industrial fuels. Fuel oil, particularly, can usually be purchased on a basis of

specifications more or less prescribing a fuel of definite composition reasonably free from impurities. The difficulty, however, lies in its combustion. Fuel oil, prior to combustion, must be first atomised, vaporised, and gasified, and this general complexity brings about conditions where it is difficult with simple equipment to obtain definite characteristics of combustion.

From the standpoint of utilisation, however, fuel oil can be considered as a semi-refined fuel, and its application to many industrial processes which are semi-automatic in operation would be much more common were it not for the fact that the price of fuel oil is relatively high and the availability from the standpoint of a large and permanent source of supply at a non-prohibitive price is indefinite.

Gas is a prepared and refined fuel. It can be manufactured so that its composition is definite, it is free from impurities, and its characteristics of combustion cover the proper range for the work we have in mind. Gaseous fuel of the proper composition can with simple equipment be burned at a very slow rate or with exceptional speed. The temperatures can be as low or as high as desired, and the application of the fuel is unusually practical in so far as the ability to localise heat at those points where the heat is desired to perform necessary work is concerned. Gas in its combustion is positive and accurate, and gaseous fuel of the proper chemical composition fully meets all the requirements of the ideal industrial fuel.

There is another source of energy which is ideal from the standpoint of its utilisation in the modern industrial furnace, and that is electricity. The conversion of electrical energy into heat energy is simple and inexpensive, and the temperature and the quantity of heat developed can be easily controlled with the greatest accuracy. While it is true that in some cases the use of electricity for industrial heating is somewhat handicapped because of the difficulty involved in readily obtaining some specific atmospheric condition in the furnace, such as a reducing atmosphere, we may, in general, look upon both gas and electricity as ideal fuels from the standpoint of their effective utilisation. The great problem, however, of electricity as a fuel is its cost. Its comparative cost with gas can be readily understood when we realise that when we make electricity from coal we recover on the average some 15 per cent. of the heat from coal, while with a modern method of gas manufacture it is possible to obtain a thermal efficiency of gas

manufacture of 85 per cent. It is true, however, that certain modern electric generating stations on continuous runs are obtaining somewhat better than 25 per cent. efficiency. In other words, the manufacture of electricity from coal recovers 15 per cent. of the energy and wastes 85 per cent., while the direct opposite is possible with gas, namely, the recovery of 85 per cent. of the energy of the coal with the use of only 15 per cent. of the heat for the conversion process. Fundamentally, therefore, from a cost standpoint, gas can be made considerably cheaper than electricity, and as we look toward the future we must consider gas as the more logical fuel of the two. Gas as an industrial fuel appears to be the sound solution of our problem.

From an industrial standpoint, producer gas is a most important fuel, since we consume annually in the United States approximately 25,000,000 tons of coal in its manufacture. Because of its low cost of manufacture this gaseous fuel is of particular value to those industries which use tremendous quantities of heat, and where the cost of fuel is a major factor of production cost and also where the specifications or combustion characteristics of the fuel are not so rigid. As an example, producer gas is being used extensively in both the steel and glass industries. In the light, however, of the trend of industry toward more exact production demands necessitating a gaseous fuel of certain specifications and requirements, producer gas leaves much to be desired from the standpoint of its utilisation. Producer gas being made from coal usually varies somewhat in its composition and B.Th.U. value, and usually contains a certain amount of impurities, such as tar and sulphur. Besides, the rate of flame propagation of producer gas is slow, so that the problem of proper temperature distribution in the furnace is difficult. Also, producer gas develops an exceptionally low flame temperature, so that in the great bulk of industrial heating operations it cannot be used unless the air and gas for combustion are pre-heated. While it is true that we can increase the flame temperature of combustion by this means, we are nevertheless limited in the maximum flame temperatures to be obtained because of the dissociation factors of the products of combustion, which generally limit the extent to which the flame temperature can be increased, regardless of how much pre-heat we put in the air and gas. Besides, pre-heating of air and gas by regeneration is usually not so satisfactory, because of the intermittent cycle of operation and the varying temperatures

of pre-heat; which, in turn, produce varying conditions of combustion in the furnace.

In general, producer gas does not fulfil the requirements of a satisfactory fuel for the mechanically-operated modern industrial furnace. The composition varies, it often contains impurities, the rate of combustion is too slow and the maximum flame temperature that can be developed is too low. The industrial plant requires a better fuel of a higher B.Th.U. value which is clean and which has greater flexibility in its combustion characteristics.

PART II

THE TREND OF INDUSTRIAL GAS UTILISATION

Steam Generation

H. W. BROOKS AND GEORGE ORROK

The part played by gaseous fuel in the raising of steam in the United States has always been of importance. Even in the earlier blast furnaces steam for the blowing and hoisting engines was generated by burning the waste gases from the blast furnace under the early egg-ended boilers. To-day every one of the 400 blast furnace stacks in the United States has a number of boilers attached to it and more than fifty per cent. of the blast-furnace gas is used for the raising of steam, the remainder being used in gas engines and the hot stoves. The production of blast-furnace gas has fluctuated between five and six million million cubic feet in the last ten years, while the pig-iron output has varied between much wider limits, from sixteen to forty million gross tons. American figures are usually given in boiler horse-power of 33,305 B.Th.U., but all the figures in this paper have been calculated as kilowatt hours at 40,000 B.Th.U. in the fuel (high heat value) where the exact equivalent cannot be ascertained. During the last five years the production of pig-iron has averaged about 100,000 gross tons per day, with an average use of 2,130 lb. of coke per ton of pig-iron. The steam power produced annually is the equivalent of about 6,000,000,000 kWh. Very little blast-furnace gas is used in other than blast-furnace or steel plants.

Boiler efficiencies have been quite low, due to imperfect burners, high dust content, air leakage, and poorly designed boiler settings. Plants built thirty years ago might average 50 per cent. efficiency. Plants built between 1905 and 1914 were capable of somewhat

higher efficiency, but in the last ten years average yearly efficiencies between 60 and 70 per cent. have been rather uniformly secured where attention has been paid to the boiler control, and proper instruments installed. Boilers of modern design are now used in many plants, suitable furnaces of larger volume are provided, modern soot blowers are installed, correctly designed mixing burners are in use, and in many plants dust cleaning apparatus is employed, which does not seriously waste the sensible heat of the gases.

Even more important than blast furnace gas is natural gas, which is produced in large quantities and in widely extended localities in the United States. While the thermal content of blast furnace gas rarely exceeds 100 B.Th.U. per cu. ft., natural gas, when composed of nearly pure methane (CH_4), as in the Louisiana (Caddo) field, will have a heat value of about 1,050 B.Th.U. per cu. ft. When appreciable percentages of ethane (C_2H_6) are present, as in certain Kentucky and Pennsylvania fields, the heat content may exceed 1,500 B.Th.U. When the gas carries much nitrogen the heat value may fall below 700 B.Th.U., but on an average the heat content over the whole United States is not far from 1,000 B.Th.U.

The statistics collected by the U.S. Bureau of Mines show that natural gas production has nearly doubled in the last ten years' period, and in 1927 exceeded 1,400,000,000,000 cu. ft. The largest producing states are Pennsylvania, West Virginia, Ohio, and Kentucky in the East, Louisiana, Arkansas, Oklahoma, and Texas in the South, and California in the West. Each of these fields is connected with the adjacent country by a network of pipe lines, in some cases as large as 30 in. in diameter and over 450 miles long, through which the gas is pumped at high pressure to the distribution points. Of the total production about 37 per cent. is used in the fields or for compression, about half and half in gas engines and in steam making. The manufacture of carbon black absorbs roughly 10 per cent. The balance, about 53 per cent., is distributed to industrial and domestic customers. The domestic use is around 290,000,000,000 cu. ft., leaving 450,000,000,000 cu. ft. for industrial use.

The Central Station industry uses roughly 65,000,000,000 cu. ft., generating about 3,000,000,000 kWh., about 3.75 per cent. of the total United States Central Station output in 1927.

Statistics regarding the 385,000,000,000 cu. ft. used in industrial

plants other than Central Stations are very hard to secure. Many of these plants are both producers and users, but it has been roughly estimated that about one-third, say 130,000,000,000 cu. ft., is used for the raising of steam for the production of power, 225,000,000,000 being used in industrial furnace operations, such as iron and steel works, brick, cement, and glass industry, metallurgical furnaces other than iron, and the chemical industry.

Natural gas is used for the generation of steam in innumerable industrial plants, the largest users being the paper and pulp mills, sugar mills, cement plants, and other chemical operations requiring large quantities of steam.

Gas burners, whether for high or low pressure, and for gas of any heat value, are usually mixing burners of the Bunsen type which have been developed from the simple pipe orifice used with blast-furnace gas at the hot stoves. Venturi tubes with both sliding and damper adjustments, with or without mixing vanes, have been added to secure proper mixing. With blast-furnace gas flame propagation is naturally slow, and the best results can only be obtained by perfect mixing. Single burners firing as much as 24,000,000 B.Th.U. per hour of blast-furnace gas have been successfully used. Natural gas has been burned in very much smaller burners, as many as 150 being used on a single boiler of, say, 6,000 sq. ft. surface, with good efficiency. These small burners are Bunsen burners with a 3 in. air tube, and the gas pressure used is of the order of 3 to 5 oz. More modern burners are adapted to higher gas pressures and resemble pressure oil burners. The latest types burn up to 50,000,000 B.Th.U. per burner, using gas from 16 to 20 lb. pressure. Most of these burners are of the combination type, where the oil tip can be withdrawn out of the heated furnace in a very few minutes when gas is to be used.

Theoretically, blast-furnace gas is an excellent fuel for steam raising, as the hydrogen and moisture content are quite low and the possible boiler efficiencies are high. Practically, the dust content in most cases is so large that actual efficiencies over a year rarely exceed 65 per cent. When wet cleaning is used the moisture loss is lowered and the sensible heat is lost, but with efficient dry cleaning efficiencies over a year of 70 per cent. have been reported. Test figures above 80 per cent. have been reported by careful experimenters.

Natural gas, with its large percentage of hydrogen, is at a disadvantage, as the hydrogen and moisture losses are rarely less than 12 per cent. Test results of 80 per cent. efficiency have been reported from a few plants even with this handicap, but 75 per cent. to 77 per cent. may better represent the efficiency for a yearly period. Several central stations using natural gas as a fuel have yearly records better than 18,000 B.Th.U. per kWh.

Summarising :—

Blast-furnace gas is now used for the raising of steam, equivalent to	6,000,000,000 kWh.
Natural gas is used in the central station industry generating	3,000,000,000 kWh.
Other industries use natural gas for steam raising equivalent to	3,200,000,000 kWh.
A total of ...	12,200,000,000 kWh.

Equivalent to about 15 per cent. of the central station production of power.

	Tons of coal
The total quantity of blast furnace gas made is 6,000,000,000,000 cu. ft., equivalent to	17,900,000
The total quantity of natural gas produced is 1,400,000,000,000 cu. ft., equivalent to	44,600,000
Total gas production equivalent to	62,500,000

or about one-tenth of the yearly coal production of the United States.

THE STEEL PLANT

C. W. BERGHORN

The steel plant aims to be a completely balanced organisation, bringing into its walls either from its own lines, or outside interests, only ore, flux and fuel. The output of a steel plant aims to be nothing but finished steel, slag, and similar by-products. When such an organisation is using different types of fuels, it is necessary to have flexibility in the use of fuels in one or more of the important and large fuel-consuming departments.

Generally, the boiler plant is a dumping ground for the excess fuel. Boilers are, therefore, equipped to burn either coal, oil, coke-oven gas, or blast-furnace gas, or combinations of any of

these fuels. As a rule, the other fuel-using departments are given specifically one type of fuel per furnace, although there may be any one or all four of the fuels used in the same department.

A change has taken place in the production of coke for foundry uses. The Bee-Hive oven is making way very rapidly for the by-product coke oven. This change is evidenced by the production of 5,607,899 net tons of by product coke in 1907, while in 1926 the production was 44,376,586 net tons. A technical advance in the operation of some by-product coke-oven plants, as explained by William A. Forbes in a paper entitled "Technological Problems of the Steel Industry," presented before the American Iron and Steel Institute, October 28, 1927, is the heating of the ovens with coal-producer gas, conserving for the city supply the entire production of the higher heating value coke-oven gas.

Greater economy in burning coke-oven gas in heating furnaces of various types has been developed at some steel plants by furnishing the gas to the burner system at an uniform pressure of from 10 to 15 lb., this gas utilising the pressure to inspirate a correct volume of atmospheric air for proper and efficient combustion. This practice results in a marked increase in production, with a correspondingly large reduction in the gas used per unit of product. At the same works, certain types of heating furnaces and soaking pits were equipped with the low-pressure system, where fan air, at 1 to 1.5 lb. pressure, inspirates gas at about atmospheric pressure, resulting also in increased production and decreased fuel consumption.

Experiments are being conducted at some steel plants on low-temperature carbonisation of coal for the production of good fuel gas. Complete gasification of a good grade of bituminous coal will give from 45,000 to 50,000 cu. ft. of 370 to 385 B.Th.U. gas per ton Before this gas can be satisfactorily used for distribution by public utility companies in existing pipe lines for domestic or normal industrial purposes, it must be enriched to the usual standard of approximately 540 B.Th.U. It is possible that this enrichment may be provided by the more accurate fractionation of the natural gas gasolines now being produced by some of the south western oil plants.

Important changes are taking place in the design and construction of open-hearth furnaces to follow the trend in fuel utilisation. These newer designed furnaces give increased life, and will produce more steel without the necessity of shutting down for

repairs. An important change in open hearth practice has been the general increase in the use of coke-oven gas and tar for melting and a decrease in the use of producer gas and natural gas

The following figures show the proportion of total open-hearth steel ingots and castings made by an important steel interest for the years 1920, 1923, and 1926, according to the kind of fuel used in melting. The amount of castings involved does not in any way change the proportions furnished.

Open-hearth Steel Ingots and Castings made in the years 1920, 1923 and 1926, showing proportion of total tonnage made according to kind of melting fuel used

Fuel used	Year 1926 per cent	Year 1923 per cent	Year 1920 per cent.
Producer gas	40·6	44·5	50·1
Tar alone	10·6	6·4	—
Coke-oven gas alone	3·8	5	—
Fuel oil alone	2·7	3·9	5·5
Natural gas alone	2·7	4·9	5·3
Powdered coal alone	—	—	·5
Coke-oven gas and natural gas	13·1	10·4	11·8
Coke-oven gas, tar and fuel oil	3·9	1·6	—
Coke-oven gas and tar	16·2	24·3	23·5
Coke-oven gas, natural gas, tar and fuel oil	6·2	2·3	—
Tar and fuel oil	2	—	3·3
Blast furnace gas, fuel oil and tar	—	1·2	—
Total	100·0	100·0	100·0

To some extent these figures indicate the general trend throughout the steel industry There has been a drop of approximately 10 per cent in the use of producer gas, and an increase of a like amount in the use of tar alone, as a melting fuel.

For a few years prior to 1920, powdered coal was used, particularly in the Pittsburgh district, replacing natural gas during the winter months, when low pressure and domestic needs made the latter fuel unavailable.

In the item of coke-oven gas and natural gas, shown for the year 1926, as 13.1 per cent., approximately 60 to 70 per cent of this combination was coke-oven gas.

In the items of coke-oven gas and tar, the former fuel ordinarily approximated 50 per cent. to 60 per cent. of this combination.

The two items of coke-oven gas, tar and fuel oil, and coke-oven gas, natural gas, tar and fuel oil are so shown because these fuels were at times used in combination, the proportion depending upon the amount of each fuel available. Coke-oven gas and tar furnished by far the larger part of these combinations.

There were three main fuels used in 1926, namely, producer gas, tar and coke-oven gas, with fuel oil used to fill in, or in some special cases as the sole fuel.

Since the year 1923, experimental work has been carried out, with some degree of success, on the use of blast-furnace gas in combination with fuel oil and tar, and blast furnace gas with producer gas, for open-hearth melting, and also for use in reheating furnaces. Blast-furnace gas has also been used experimentally for blowing gas producers in place of steam. While nothing as yet has been done in this country paralleling the European practice of utilising a mixture of coke-oven gas and blast-furnace gas as an open-hearth fuel, there are expectations that the possibilities in this field will be exploited.

As installations of new by-product coke ovens are made, a larger supply of coke-oven gas and tar will become available for melting purposes, and will no doubt largely replace some of the producer gas and natural gas now being used.

In 1920, open-hearth operators did not regard coke-oven gas, when used alone, as particularly desirable, because of its low luminosity. Since that time the steel industry has made considerable progress in its use, a few plants in particular having operated very successfully when using only coke-oven gas. The furnace construction with this fuel is quite simple and inexpensive compared to producer gas furnaces. It does, however, require some education in its proper use, because of its lack of illuminants. One difficulty encountered in many plants has been the increase in the sulphur content of the steel, due to the sulphur content of the unpurified coke-oven gas. This can be, and has been, avoided by the maintenance of a uniformly fairly low-sulphur iron. Others have found that the use of high-manganese pig-iron will help considerably in controlling the sulphur. Still another method of overcoming this trouble, where it exists, is the washing of sulphur out of the gas by various means.

The greater production necessary from reheating furnaces for rolling billets, has brought about a wide change in the furnace equipment and fuel used for reheating operations. The stationary hearth type, using cranes for loading and unloading, except for jobbing operations, has been largely discarded in favour of the continuous type pusher billet furnace with water-cooled skids. The cold or relatively warm billets are loaded at the inlet of the furnace and pushed along water-cooled skid rails toward the

burners, which are generally located near the outlet end of the furnace. The completely proportioning burners direct their heat toward the oncoming row of billets. At a point about six to ten feet before the discharge end, the water-cooled skid rails give place to a magnesia or chrome hearth to heat up the spots which were in contact with the water-cooled rails. The products of combustion gradually give up their heat as they meet the advancing cooler billets, until the cold flue gases are discharged at a point close to the inlet of the furnace. The substitution of this type of furnace for previous batch type furnaces has made possible substantial savings in the fuel requirements of reheating.

In a continuous billet furnace, the fuel consumption is approximately 3,500 to 4,000 cu. ft. of 540 B.Th.U. gas per gross ton of billets, compared with approximately 6,600 cu. ft. of gas per gross ton with a batch type furnace. These gas consumptions will vary, depending on the relative temperatures at which the billets are charged.

One of the most interesting problems with which the sheet steel manufacturer has had to deal in the last decade is the production of material to meet the exacting requirements of the automobile trade.

The practice in sheet and pair furnaces is determined to a great extent by the size and type of material which is produced, whether it be galvanised, tin plate, or automobile sheet. The full finished sheets are given the most careful treatment, and the tendency is noted toward the introduction of a continuous sheet and pair furnace. Their value still remains to be demonstrated over a long period of time.

With the use of nickel and nickel alloy the practice in the steel plant in the reheating of billets and the production of sheets is followed very closely.

Along with the development in the automobile industry, manufacturers in other lines using sheet steel as a basic material have been equally alert and progressive, so that we are now in the very midst of an era in which the practised art of fabricating, stamping and deep-drawing sheet metals is little short of amazing.

In the production of deep-drawing steels a great change has taken place in the process. Years ago most of the sheet annealing took place in boxes in which the sheets were stacked and slowly annealed in a dead atmosphere. By sufficiently slow heating the temperature was found to be quite uniform, and good soft sheets

resulted. With the increased severity of operations for automobile use, a sheet was necessary, which was tough but not hard, although not soft. The process of box annealing was supplanted by an individual open annealing, in which each sheet was heated singly to a temperature above the critical point and cooled very rapidly in air to preserve the structure. In this operation, the desired combination of properties was obtained, relatively high yield point, high percentage of elongation, and a uniform structure of more equi-axised grains. The desired degree of toughness was imparted without brittleness and the tendency to pull coarse during stamping was overcome.

The furnaces for producing this work are all gas-fired, the automatic control being so uniform that all sheets have the same properties, and by the design of the roller mechanism which carries the sheets through the furnace, the surface of the sheets when fabricated are so perfect that the present method of finishing by the use of a few spray coats of lacquer needs no improvement.

HEAT TREATMENT OF FERROUS METALS

N. T. SELLMAN

Heat treatment of steel covers many varied and different operations. The most important of these are forging, carbonising, hardening, annealing, normalising, and blueing.

The inherent qualities of gas as a fuel can be fully realised in all of these operations, although for each operation different qualities are met. High flame temperature and close atmospheric control obtainable from gas make it important in forging and billet heating.

Gas applications to forging can be made either to job forging, where a great number of different articles are heated in small lots, or to large volume forging, where mass production of the same article is carried on.

Close regulation of furnace atmosphere eliminates to a great extent the scaling of the metal. Reduction in scaling means not only a saving in the cost of the material but also increases the life of the dies and blanks very greatly. With the reduction of scale it is estimated that 30 per cent. of the machining costs for subsequent operations are eliminated when forging is carried out in proper gas-fired forges.

Continuo[illegible] fo[illegible] billet heaters are following in general the practice of the larger continuous billet-heating furnaces. The adaptability and speed of a continuous forge can be gathered from the results which have been obtained on a production basis where billets weighing 70 lb. each have been heated for forging into crank shafts in fifteen minutes. Twenty-five billets are heated in a continuous forge at a time and the operating costs have been reduced over 25 per cent. as compared with the stationary oil-fired furnaces at a much lower B.Th.U. fuel cost for oil.

Carbonising is following two lines. For large production the continuous counter-flow furnace, automatically controlled and with a pusher is being used. For large volumes of smaller articles the tendency is toward the rotary retort method using gas atmosphere for the carbonising medium. Both methods fit in with the modern trend of making gas fuel only incidental in the continuous manufacturing process.

The continuous pusher type carbonising furnaces employ the pack carbonising methods and boxes. The boxes are inverted; the covers serving as supports ride on alloy hearth rails through the furnace. As in all continuous furnace operations involving a slow heating up and a soaking period, the products of combustion are discharged from the furnace at a point where the cold incoming work enters. In this way, the maximum heat is utilised in heating the materials and losses reduced to a minimum.

In the rotary retort carbonising machines the carbonising material is entirely eliminated, and instead, the retort which carries the steel articles has a constant small flow of city gas. The gas acts as carbonising material and eliminates entirely labour for packing boxes and carbonising compound. The result is that a great saving can be made by reduction of labour and materials and again the higher cost B.Th.U. fuel applied.

To discuss all the various types of hardening applications would lead into great length and much detail. The characteristics of gas combustion, namely, flexibility, close temperature control, constant atmospheric control, and efficient applications make the use of gas very widespread and desirable for all hardening operations.

In the small heat treating room the flexibility and quick heating up of gas make its use almost universal. No fuel storage is

required and no fuel and ash handling. Widely differing hardening operations can be carried out to meet the requirements of even the smallest jobbing shop with no loss of time.

In the larger production of continuous wire mills the hardening of automobile parts, locomotive axles, or any similar operation, the unvarying heat production made possible by gas means constant and uniform operation hour after hour, day in and day out.

Automatic control on equipment of this kind is easily applied. The constant furnace atmospheric conditions in the furnaces in many cases more than off-set the cost of fuel. This was shown by the case of a wire mill where wire was heat treated directly in the furnace atmosphere. The saving in scale was sufficient to pay the entire cost of gas fuel at $.75 per M. cu. ft. In addition to this saving in fuel there was a greater production of finished wire, which meant increased profits. Similar accomplishments are usual in all classes of hardening and annealing operations.

The most recent development in continuous hardening and annealing furnaces are those which were made by the manufacturer of small parts, who designed a continuous heat treating furnace using a belt conveyor which is available for any heat treating operation where large quantities of small parts must be heated. The applications have varied from heat treating cap screws to annealing chemical glassware. The conveyors are simple and can be removed and replaced from a 30-ft furnace in less than twenty minutes. In this way the constant urge for continuous operation of the heat treating applications and the elimination of the old bottle neck in the factory is being met.

While the large volume continuous hardening and annealing may be most spectacular, the great volume of small plants making use of gas for heat treating operations brings a steady industrial load to the gas utilities.

HEAT TREATMENT OF NON-FERROUS METALS

A. M. APMANN

Whenever we attempt to analyse the part any particular commodity, such as the non-ferrous metals, plays in the general scheme we are confronted with a utilisation too general to be accurately determined or described. The general public thinks of iron and steel as the great factors in modern production. Our

bridges, our sky-scrapers, and our locomotives are all of steel and iron. Although the non-ferrous metals do not play so conspicuous a part, our modern civilisation can no more afford to dispense with the use of them than it can afford to return to that period of civilisation before the use of iron was discovered.

Our systems of communication are all in some way or other dependent on the non-ferrous metal industry for their success. The telephone cables carrying the wires over which our messages are transmitted are covered with a heavy lead coating, upon which they rely to combat corrosion. The non-ferrous metal arms of the relays in the various exchanges are constantly operating the intricate telephone apparatus—from the signal light to the calling of the other party.

The newspapers of the metropolitan New York districts alone used during the year 1927 500,000,000 cu. ft. of gas to melt the lead required for stereotype work. It is estimated that for the country as a whole 4.5 billion cu. ft. are used for this work.

Anyone who is keeping abreast with the times will talk of his radio set, and tell how he is enjoying the programme and the great distances he is getting, but he seldom thinks of the condenser Yet, upon the condenser's quality the radio engineer will tell you that the success of getting distant stations rests. The non-ferrous metal bus bar used in wiring our set makes our hobby a pleasure, as it is so easy to bend and solder. Wireless telegraph instruments, like radio, have many of their features made of non-ferrous metal.

In the early development of the automobile, all of the important parts were made of steel or cast iron, but progressive engineers began to realise the advantages of using aluminium or some other non-ferrous metal for some of the more vital parts. As a result, about 1917 the aluminium piston was introduced into the gasoline engine, and soon after engines of non-ferrous metal began to be built. The crank-case is an example of where the change from a hard to a non-ferrous metal brought about a distinct saving to the manufacturer. Aluminium is stronger and simpler to work than the usual run of metals, and involves in many cases a single casting Many of the minor parts of the control ignition magneto, carburettor, and pump systems of gasoline engines are made of some one of the non-ferrous alloys. The spark and gas levers, the instruments, and the door handles, for example, are usually made of an aluminium alloy.

With the aeroplane, progress has gone hand in hand with developments made in the use of non-ferrous metals, notably duralumin. When the latest German aeroplane, the "Junker," was put forth everyone marvelled at the step this industry was taking. This plane was made entirely of duralumin. Even the wings were formed of corrugated sheets of this alloy instead of the usual doped cotton cloth. Duralumin is composed as to about 95 per cent of aluminium. We have all heard of all-metal planes, and now we have an all-metal propeller made of forged duralumin. This aluminium alloy is used almost entirely in the internal bracing of a dirigible, and there is an attempt being made in this country at the present time to build an all-metal dirigible, the metal used being, of course, an aluminium alloy; for this is the metal which gives the greatest strength per unit weight of any of the metals now in common use.

In the marine industry we find the huge propeller bearings made of babbitt or the like. Non ferrous metals are being supplied more and more for shipbuilding apparatus, so that to-day we have large pipe tees and elbows of this type of metal. Gaskets, used to make steam lines leak proof, have a piece of lead staggered around the joining area of the flanges In railroad cars, as in subway and in trolley cars, many of the small accessories are made of similar metal. Perhaps this is not observed, but the window hinges, door slides, pulleys, window stops, door locks, and pipe connections are of this metal. In all of these cars bearings are required which are generally of non-ferrous metal. In every industry where electrical apparatus is used the fuse protects it; and in its care is safely trusted large amounts of invested capital. In the manufacture of storage and dry batteries, lead and zinc alloys make up the chief constituents of the terminals and guides.

Aluminium cooking utensils are constantly replacing the old pots and pans in every kitchen, as they are easy to clean and wear well The collapsible drinking cup, the egg holder, and the aluminium percolator are some of the newer utensils which have been placed before the public. Many fixtures of non-ferrous metal are being sold for household purposes like the brush holder and the towel rack. Very seldom does one connect the non-ferrous metal industry with the clothing industry, still there is an existing relation From the metal buttons on the workers' overalls to the weights in the women's clothes there is a large field which unites them.

One of the scientific wonders of the world is the motion picture, which is entering our lives both from the educational and recreational viewpoint. In order that the projecting machine might have a good support engineers adopted an aluminium alloy frame. This is only one of the many uses this metal is put to by motion picture projecting apparatus makers Lead, zinc, and the other non-ferrous metals are extensively employed in making toys and novelties. Almost all of the metal parts of the camera must be light and strong, so that the designer always specifies one of the non-ferrous metal alloys when adopting a metal for these parts. Many people know that Thomas A. Edison invented the phonograph, but very few notice that almost every machine has non-ferrous metal parts, generally of aluminium. The latest advancements in player pianos and electric organs warrant the use of cheap but strong metal in many places. The manufacturer has met this want by using white metal alloy parts. The non-ferrous metal compounds also find their way into the schoolroom, business office, and other places where the pen and pencil come into work. To-day the nickel-plated pencil and the non-ferrous metal pen point are necessities of the day When the cross bars of the telephone poles get too numerous the telephone companies remove the pole entirely and gather all of the cables into a lead conduit which is placed under ground. The plumber uses lead conduit and solder bars in all branches of pipe working.

The use of copper base alloys, however, probably surpasses in amount and number the use of all other non-ferrous metals. Copper and brass, because of their resistance to corrosive agencies, are used in large quantities for piping water and for handling corrosive liquids. The use of copper and brass alloys for resistance to atmospheric conditions in the case of roofs, drain pipes, and fly screens, has been widely advocated and used.

The electric conductors would be very massive indeed were it not for the high conductivity and low resistance of copper and its alloys.

An example of the size of the copper industry can be gained when it is known that there are approximately 8,900 brass foundries casting various grades and types of brass in the United States proper.

Non-ferrous metals, because of their close adhesion to steel and their resistance to corrosion, find extensive use in galvanising, sherardising and tinning, while the desire for more attractive

household utensils and the fabrication of larger one-piece articles has made it necessary successfully to anneal large sheets of non-ferrous metals, so that they can be easily and simply stamped, drawn, or spun, into the desired finished shape.

The use of gas in the various non-ferrous metal fields is increasing at a tremendous rate. A large percentage of the aluminium ingots are melted in gas-fired reverbatory furnaces, and after casting are heated before rolling in continuous billet-heating furnaces similar to those discussed under the steel plant. After the sheets are drawn the aluminium utensils and parts have the stamping strain removed by annealing in continuous basket type or plate convey type gas-fired furnaces. Extrusion presses continuously force the lead conduit which is used for plumbing work, and for covering electrical conductors in an unending length. In many cases the cable, after being wound, is directly coated with lead covering at the outlet of one of these gas-fired extrusion presses. The temperature control at the point of covering is so delicate that the lead alloy must be kept in a mushy condition, neither entirely solid nor entirely liquid. On the other hand, the melting pot must have sufficient capacity rapidly and cheaply to melt all the lead which is necessary for this great production operation.

The use of gas for die-casting aluminium and brass is very wide-spread. Gas finds its application in making the base concentrated alloys which are later mixed with aluminium to give the die-casting the desired composition, and in heating the reservoir of the die-casting machine proper.

The trend toward gas utilisation in the brass industry is manifested in the development of new metal retort furnaces, which eliminate much of the labour previously used in the crucible type furnace by tilting and emptying their charge directly into the moulds. The close control of temperature possible in tinning baths to prevent flashing of the oil covering, and to give a uniform coating, makes it necessary to use the very refined and over-all inexpensive gas fuel.

In the galvanising of iron and steel articles, the nature of the dross which is formed between the zinc oxide and iron, calls for a unique application of heat, which can be supplied alone by the radiant energy and rapidly conducted heat of properly designed gas-fired equipment.

FOOD PRODUCTS

H. O. ANDREW

Of the three basic necessities of life, which are food, shelter, and clothing, none is so fundamental as food. As a testimonial, therefore, of the value of gas in everyday life, it is peculiarly fitting that this fuel occupies such a prominent place.

In the production of food products the inherent advantages of gas, such as flexibility, control of time and temperature, space saving, etc., all play their part as in all other industrial processes requiring heat, but with special emphasis on the factor of cleanliness. For with food it is far more essential than with metal parts, cores, machinery, etc., to insure cleanliness and freedom from contamination as well as quality of product.

It is a well-known fact that taste is one of the most sensitive of the senses, to such a degree that certain foods cannot be placed in the same refrigerator without absorbing undesirable flavours. When the permeating qualities of such crude fuels as oil and coal are considered the paramount advantages of gas are readily realised.

In point of volume, the greatest quantity of gas consumed in the production of food products is for cooking. Some 10 per cent. of the total manufactured gas consumed in the United States is used for this purpose by hotels and restaurants alone, without counting home cooking. Manufactured gas is so well adapted for the work that in large metropolitan areas, such as Chicago and New York, about 80 per cent. of this total commercial cooking load is now on gas. Future growth of this activity will come primarily from enlargements in population and the extension of gas service to rural communities, now totalling about 50 per cent. of population where such service is not now available.

The hotel and restaurant load is particularly desirable to the gas company, because most of this commercial cooking is done at "off-peak" hours, with a result that a minimum investment is required by the utility to supply service. No other load, including even the general industrial, affords this advantage to such an extent. Progressive utilities have been quick to realise the importance of this consumer, and in addition to supplying fuel they maintain a separate hotel and restaurant department and send representatives at regular intervals to inspect equipment, offer suggestions for improvements, and do everything possible to make a satisfied customer.

In the food products field probably no other application offers the possibility of expansion presented by the bakers. Bread baking, now carried out by competitive fuels, represents to gas companies a potential load of 45 billion feet, conservatively estimated, or equivalent to a 10 per cent. increase in present national manufactured gas consumption.

At the present time bread baking is drifting more and more from the small retail manufacturer to more powerful hands, which combine national organisation with large local producing centres. This indicates that the great bulk of baking will be done in large equipment by big concerns under intense competition.

Realising these facts the Research Committee of the American Gas Association, co-operating with the American Institute of Baking, have expended considerable time and money in developing a new bake oven with special operating advantages in fuel economy and flexibility, with which it is expected a large percentage of this market will be obtained. In many ways meat smoking is a cook's job, and the methods employed are as variable as those used by all good cooks. Nevertheless, by the application of the elementary principles of drying, together with the use of a flexible and controllable fuel, universal standardisation and quality of product may be obtained with marked decrease in shrinkage, or the tendency of meat to lose weight after it has been smoked. Because of this, gas plays a vital part in the smoker's work The five important factors are shrinkage, time, temperature, ventilation, humidity and quantity of smoke; and by the use of gas all these are placed under exact control.

In the roasting of coffee, cocoa, and peanuts, practically all modern equipment is gas fired. Increased capacity, speed in roasting, and greater production per individual attendant, all make gas fuel a necessity to successfully compete with up-to-date firms. Here again the advantages of temperature and control appear, and by virtue of its cleanliness gas may be sometimes burned, as in coffee roasting in direct contact with the product, with consequent high operating efficiency and uniform quality of product.

In pasteurisation, canning, syrup boiling, fruit ripening and a host of miscellaneous activities, gas plays its part. It is the one fuel that meets ideally the pre-requisite conditions of cleanliness and quality as demanded by the findings of modern science and an ever-increasingly fastidious public.

CERAMICS

HENRY L. READ

The first and most important problem to be overcome in firing practically all classes of ceramic materials is that of control of the atmosphere immediately surrounding the ware. But obviously the expense of installing and operating proper control must be less than the losses caused by its non-use.

In the firing of ceramic materials specific terms based on actual furnace atmospheres are often misleading, as the progressive stages in the firing of ceramic materials result in changes which are the results of relative furnace atmospheres, rather than "oxidising," "reducing," or "neutral" conditions.

With coal, conditions are bound to be more reducing in the furnace gases after charging and more oxidising when the fires have burned down. If it were not for the air let in over the fire and directly into the bag walls, coal-fired kilns would be alternately wholly reducing and wholly oxidising, and would affect the ware even though muffled or saggered

With oil as fuel, firing conditions are greatly improved over coal firing since the periodical cleaning and recharging of fires is eliminated Fluctuating furnace atmospheres still may, and do, occur unexpectedly, however, due to variations in pressure on oil and air or steam lines, stoppages in oil strainers and needle valves, variations in draught, etc.

Electricity has in the last few years come forward strongly in the ceramic field as a heating medium. Its high cost per B.Th.U. has often been more than offset by its cleanliness and ease of operation and constant oxidising atmosphere. It has hitherto laboured under the disadvantages of lack of a wide range of temperature control and danger of breakdowns. The metallic ribbon resistors used seemed to lack the requisite ruggedness.* A far superior type of heating element has been lately developed. hence keener competition from electricity is expected. But this fuel will always be handicapped by high unit cost, partly offset by excellent performance.

Gas has been steadily receiving more and more attention in ceramic work. There are certain ceramists of the old school who claim that it may be all right for many operations, but that with it

* See *Journal of the American Ceramic Society*, 9, 797-804 (1926), for description of electric v. gas furnaces in enamelling cast iron.

heat distribution cannot be obtained evenly in the large round draught kilns. This statement is not correct.

Muffle furnaces are used to insure uniformity of heat, to keep dirt and unburned carbon from the ware, and to eliminate or greatly reduce the amount of flue gases in contact with the work. They serve these purposes, but at the cost of many more heat units than are required by open furnaces, and there is the expense of renewing the muffles.

Gas furnaces are easily built without muffles and give perfectly even temperatures throughout. The question of dirt and unburned carbon in the absence of a muffle may be serious even with gas, since often dust is pumped into the burners from the atmosphere. Then, too, little pieces of brick or fireclay may drop from the arch upon the ware or be picked up and deposited by the rapidly circulating gases. Except with an excess of oxygen tiny particles of unburned carbon will spot the ware. A muffle is an excellent protection against such contingencies. Yet it has been demonstrated that by cleaning the air entering the blower, with automatic proportioning of the air and gas, and by painting the inside of the furnace with a suitable glaze or vitrifiable wash, muffles are not necessary when gas is used.

The loss of ware in firing is an item of importance. Kiln losses are expensive, and effort to avoid them is justifiable. A more costly fuel would be justified if the percentage of pieces spoiled in the kilns is thereby appreciably reduced. A manufacturer of electrical equipment fired porcelain to cone 11 with coal in a tunnel kiln. When the kiln was altered to burn 525 B.Th.U. gas, the number of pieces rejected was so greatly reduced as to justify gas costing about $100 per day in place of coal costing approximately $35 per day; and in this case the production was increased 5 per cent.

One of the many advantages of a tunnel kiln is the space-saving possible. Because of the relatively small volume of the firing chambers and the refined temperature gradient, the multiplicity of small sized oil burners makes tunnel kilns which are constructed for combination gas and oil firing extremely wasteful of gas. In one case it was estimated that 15 per cent. more gas was used in a combination gas and oil tunnel kiln than should have been the case if a properly designed gas tunnel kiln had been used.

As a general proposition, city gas will not prove to be the cheapest fuel if applied to updraught kilns. These devices are

extremely wasteful of fuel. It is possible, however, to use gas economically by changing them from updraught to downdraught, as has been recently shown in a large pottery plant. By this alteration the products of combustion rise along the outer wall to the centre of the crown and are then drawn downward. In this way the maximum possible amount of heat is abstracted and utilised.

Indirect gas firing is the most satisfactory method of firing the continuous, automatic vitreous enamelling furnaces.

The steel pieces to be enamelled are first dipped and then hung on an overhead chain conveyor passing through the drying oven. The endless conveyor chain passes around a large sprocket at each end and is supported by an overhead track. In one type of the continuous enamelling furnaces the cold in-going work travels parallel to, and in the opposite direction from, the hot out-going ware, receiving considerable heat for drying and pre-heating. The high-temperature zone for fusing the enamel is at about the middle point of the kiln. This high-temperature zone is divided into two compartments through which the work to be enamelled travels in opposite directions. The products of combustion from the high-temperature zone go to the inlet end of each of the furnaces, give up their heat in pre-heating the in-going ware inside the furnace, and then are discharged at a relatively low temperature. In another type, the work travels in one direction countercurrent to the products of combustion, which are taken off at the charging end after passing through a pre-heater. The gases are then conducted to a tunnel dryer alongside the furnace. In the dryer the work passes in the opposite direction to that in the furnace At the dryer outlet the work may be removed for brushing or edging if desired, or may be left attached to the conveyor, which returns *via* the furnace. With suitable pyrometer control and automatic air-gas proportioning apparatus, either unit is probably as near self-acting as it ever can be. The only labour required on them is that involved in dipping and attaching the ware, and for removing it as it emerges. As is to be expected, the thermal efficiency is unusually high and the production rate very large.

In conjunction with enamelling sheet steel, most plants require equipment for annealing or acid scaling, or both. Such work is probably most satisfactorily done by gas in continuous automatic furnaces The temperature, 1,200° to 1,400°F., is a little too low

for oil to be entirely satisfactory, mainly because of the danger of a deposit of carbon occurring on the steel. This deposit is difficult to remove and is apt to pack in the dies. In that case, the stampings do not come out true, and excessive wear takes place on both dies and presses. If the furnace atmosphere with oil as fuel is made sufficiently oxidising to avoid free carbon, the resulting scaling of the ware is excessive. The easy control of the atmosphere and elimination of floating carbon with gas as fuel make the latter preferred in most cases.

The greatest field for gas in ceramic work probably lies in glass factories Heat is needed for practically every operation, and gas has steadily shown itself to be unequalled for the purpose. Every form of gas appliance, from little needle bunsen burners consuming a few cubic feet per hour to huge melting tanks requiring hundreds of thousands of cubic feet, are in successful and constant use. Continuous annealing leers are also gas fired economically and with low losses.

MISCELLANEOUS USES

J. B. NEALEY

The miscellaneous industrial applications of gas are almost as numerous as are the miscellaneous uses for heat. These applications may be either direct, as heating twin pots for calorising, or indirect, as by utilising steam from a gas-fired boiler in a steam jacketted kettle. There are literally thousands of such uses for gas, and it would take several books adequately to cover the subject. Hence, in this short presentation we must confine ourselves to outlining only a very few.

In the production of nickel and monel metal at the Huntington, W. Va., plant of the International Nickel Co., calcining is the first process and is accomplished in gas-fired furnaces. The Bessemer matte, as received, contains about 55 per cent nickel, 25 per cent. copper, 20 per cent. sulphur, and less than 0.4 per cent. iron. There are four calcining furnaces each 75 ft. long, 15 ft. wide, and 30 in. from hearth to crown of arch.

They are fired with six gas burners located at the discharge end, where the temperature is 2,300 F. This temperature drops gradually toward the discharge, and where it is only 500°F. excess air is forced in, to promote oxidation, and all the sulphur is burned out. The powder is moved through the furnace by thirty water-cooled arms on vertical shafts extending through the roof and driven by a line shaft with gears.

It is now in oxide form, and is reduced in more gas furnaces, after being mixed with charcoal. There are two 25-ton and two 6-ton open hearth furnaces. The larger is 18 ft. long, 5 ft. wide, and 36 in. from hearth to crown of arch, and has a 7 ft. combustion chamber. There are six burners, firing from front to rear, creating a temperature range of 2,900 to 3,000°F. Charged through the top the molten metal is tapped from the bottom in from 16 to 20 hours.

The ingots are forged from gas-heated furnaces, the blooms are heated in gas-fired furnaces for the rolling mills, and the billets are heated in gas-fired sheet and pair furnaces for the sheet rolling mills. Box annealing has been done away with and a long, gas-fired open annealing furnace is used, which is continuous and automatic in operation.

In varnish cooking exact temperature control is vital, so that fires and spoilage will not occur and gas is the ideal fuel. Following are some comparative data as between gas and electricity for fast cooking varnish and between gas and coke for insulation varnish.

Varnish Boiling Gas *v* Coke	Gas Fire	Coke Fire
Varnish boiled	1,430 gal	195 gal
Fuel used	23,750 cu ft	275 lb
Fuel per gal of varnish	16 6 cu ft	1·41 lb
Fuel cost	$0 40	$6 50 per ton.
Fuel cost per gal of varnish	$0 0029	$0 002
Labour per gal of varnish	$0 0013	$0 005
Total cost per gal	$0 0042	$0 007
Varnish Boiling Gas *v* Electricity	Gas Pot	Electric Pot
Weight of varnish boiled	1,100 lb	1,100 lb.
Total time of run	11 hr 5 min	13 hr. 28 min
Time to heat to 570 deg F	5 hr 20 min	7 hr. 50 min.
Fuel to heat to ,, ,,	2,100 cu ft	380 kWh
Fuel to hold at ,, ,,	139 cu ft per hr	13 4 kWh.
Total fuel used	3,000 cu ft	456 kWh
Fuel cost	$0 50 per M	$0 008 kWh
Cost of run	$1 50	$3 65
Net efficiency (heating up)	27 8 per cent	32 1 per cent.
Overall efficiency	16·4 per cent	19·3 per cent.
Fuel per gal of varnish	21 4 cu ft	32 6 kWh.
Cost per gal. of varnish	$0.0017	$0.0026

Lithographing at the Anchor Cap & Closure Co. is accomplished by the aid of gas heat. Here modern rotary lithograph presses are connected directly with the drying ovens by travelling conveyors. The lacquer ovens are divided into two sections, as the coating must be applied to one side and then to the other with a

drying in between. A recent installation here is said to be the largest lacquer oven in the world, being 122½ ft. in length.

These ovens are all fired with gas directly except the latter, which has a separate air heating chamber and the hot air is blown in. The advantages of the continuous gas-fired drying oven over the steam-heated in-and-out type are obvious. Formerly, when the latter type oven was charged the labourers had to stand idle from three-quarters of an hour to an hour while the work was drying. Furthermore, there was always some moisture on the lower part of the sheets when removed. In the newer ovens the operation is continuous, and the capacity of each unit is greatly increased.

The latest model, indirect heat, lacquer oven is as much superior to the direct-fired type as is the direct-fired to the older steam-heated periodic type. Some points of superiority claimed for the latest model are as follows:—

1. The circular construction assures a free and even distribution of heat in direct contrast to the formation of air pockets formerly encountered. This means that the sheets are baked uniformly and are never darker on one side than the other.

2. Baking absolutely white is an accomplishment of this new oven. It was never possible to go beyond a temperature of 225°F. in the old types without burning. In the newly designed unit, a heat of 245°F. can be maintained without any discolouration whatever showing on the work.

3. The product is baked clear through in the new ovens, contrasted with a superficial bake, where the surface was simply hardened.

4. The product from the new unit has a much richer finish.

PART III

GROWTH AND FUTURE TRENDS

J. P. LEINROTH

It was not until 1905, or only twenty-three years ago, that manufactured gas began to be used to any considerable extent as an industrial fuel. It is interesting to note that in 1905 the total sales of manufactured gas in the United States were less than 120 billion cubic feet, as compared to present sales of some 500 billion. Of this total, sales for industrial purposes now represent nearly 137 billion cubic feet, or more than total sales in 1905.

It is also interesting to note that it was in 1882 that the first electric central station was built, which, in spite of the loss of the lighting load, marks the date when the manufactured gas industry really began to expand.

Statistics for more recent years show a consumption of manufactured gas for industrial and commercial purposes of 70.4 billion in 1919 and 136.4 billion in 1927—an increase of 93 per cent. in this eight year period. The use of natural gas as an industrial fuel increased even more rapidly from a total of 490.2 billion in 1919 to 1,023.7 billion in 1926, or 109 per cent. The industrial use of coke-oven gas in the period 1919-1925 increased from 366.2 billion to 550.9 billion, or 50 per cent.—while blast-furnace gas showed a smaller increase of approximately 30 per cent. in this period. The data are given in Table A opposite.

While these percentages, particularly those relating to the use of manufactured and natural gas, indicate a very healthy growth, yet there is every indication that, due to certain economic changes which are showing themselves in the industrial world to-day, this growth will be more rapid in the years to come.

The twentieth century ushered in a new era in the industrial world. The scientific management era really started at that time. Since then we have seen the great development of scientific management in the factory.

Scientific management brought with it scientific cost accounting There is a growing tendency among progressive manufacturers to know their costs of production more accurately. We find to-day that fuels are compared less and less on the basis of the amount of heat that can be bought for a dollar, and that there is a greater realisation of the many factors besides fuel cost that enter into the final cost of the heating process. With more refined systems of cost accounting the amounts chargeable to space, depreciation, labour, spoiled work, maintenance and repairs, etc., are more accurately known and their effect on the final cost of the product more closely studied. Just as the factory manager knows to-day that high wages are not always synonymous with high production costs, so also does he realise that low fuel costs do not necessarily mean low unit costs. The advantages of higher-priced fuels, both tangible and intangible, are being carefully weighed before making decisions as to the fuel to be used. In making a decision as to the kind of fuel to use, the manufacturer, therefore, is interested in obtaining the fuel which has the best "form value" for the work

TABLE V

STATISTICAL DEPARTMENT, AMERICAN GAS ASSOCIATION, INC.

Consumption of Gas for Industrial Purposes in U S , 1919–1926, in thousand cubic feet.

	1919.	1920	1921.	1922	1923.	1924.	1925.	1926.	1927.
Manufactured gas utilities' sales for industrial and commercial purposes. M cu ft	70,380,000	69,720,000	70,671,200	80 565 000	92 424 616	105 997,700	113,000 000	126,405,000	136,400,000
1 Natural gas M cu ft.	490,[illegible]73,000	512,209,000	413,718,000	508 133,000	729,917 000	856,330,000	916 293,000	1,023,678,000	—
2 Coke-oven gas from by-product ovens not including sales to public utilities. M cu tf	366,190,000	412,896,000	257,513,000	377,692 000	523,467,000	464,825,000	550 909,000	—	—
3. Blast furnace gas used as fuel for steam and for gas engines, coal equivalent, tons of 2,240 lb. ..	7,259,875	—	4,714,898	—	9,020,990	—	9,409,936	—	—

Note 1. From Bureau of Mines —Mineral resources.
2 " " " " "
3. " " Census—Census of manufactures

at hand, the one which will enable him to maintain and control conditions best suited for the work, and the one which will give him the lowest unit cost when all items are considered.

The factory manager is particularly interested in being able to speed up his production, and guards carefully against shut-downs. He knows full well that increased production decreases the overhead per piece and that in the operation of any of the modern production systems involving planning, scheduling and routing, shut-downs are fatal. He knows the effect of forced interruptions on labour, particularly if the latter are on some form of rate which makes their daily wage a function of the number of pieces turned out. He knows the effect on the morale of the workmen of forced interruptions, and usually knows with a fair degree of accuracy what a furnace shut down means to him in dollars and cents. He, therefore, is willing to pay a premium for a fuel which will make for steady production. Continuity of operation is essential to a well run factory; it will become increasingly more important as modern production methods are more and more applied.

With the advent of labour organisations and high wages, the human element, especially where skilled labour is employed, brings to him a real problem. The labour question to-day receives a great deal of attention. The factory manager strives not to be at the mercy of skilled labour, and takes kindly to any device which will do the work with unskilled labour in attendance. Hence the great development of automatic and continuous processes in recent years. Low labour turnover is a goal for which every factory manager strives. The effect of cleanliness, sanitation, low fire hazard, and improvement in general working conditions on attracting and holding workmen is well known.

These tendencies favour the use of gas as an industrial fuel. Certainly the fact that solid and liquid fuels must first be gasified gives to gas a distinct advantage in that it makes for simplicity, which in turn makes for fewer interruptions and makes it an easier fuel to apply to automatic and continuous ovens and furnaces. It also results in a cleaner shop and an improvement in general working conditions.

The present industrial era is calling for more rigid specifications to be lived up to. Higher quality goods bring higher prices, and rejections cut deeply into profits. For every heating operation there are certain conditions which make for optimum results.

There is a certain best temperature which must follow a certain best temperature gradient, a certain best furnace atmosphere and a certain best speed. Any deviation from these conditions means a deviation from optimum results. Scientific management has as one of its objects the determining of these best conditions, and much time and money is being spent in laboratories in working them out. Furthermore, there is every indication that our industrial efficiency will call for determinations of this character being made more and more in the future. If the manufacturer is to approach these best conditions he must have a fuel which is flexible and easily controlled. Thus the item of control is becoming more important in industry. Under scientific management it becomes the crux of the whole situation, and as this becomes more and more to be the case the fuels that are not susceptible to close regulation must give way to those that are. It must also be borne in mind that a fuel that does not lend itself to good control not only affects the quality of the product but also the maintenance and life of the furnace, which in turn are reflected in higher labour costs and fixed charges. It is also obvious that the less controllable fuels are at a still greater disadvantage when used in connection with continuous furnaces in which control becomes a still more important consideration.

If there is one outstanding advantage that gas has over other fuels it is the advantage of being controlled within narrow limits. This, of course, is largely due to the fact that the gasification process necessary when solid and liquid fuels are used, is eliminated with gaseous fuels.

The future cost and supply of the fuel is another factor that must be carefully considered, as it is oftentimes necessary to make large investments in the way of heating equipment and auxiliary apparatus. Will the price of the fuel go up or down in the years to come? Is there any likelihood of an interruption in its supply? The present prices of coal and fuel oil are, in many cases, below the cost of production and so must ultimately work higher. On the other hand, by improved production and distribution practices, every evidence shows the price of manufactured gas to be in a downward trend—particularly as concerns the large-scale industrial user.

In the transformation of raw materials into final products, executives are concerned entirely with the lowest overall cost per unit of product, and with contributing production charges

only as they tend to raise that figure. Thus it does not matter how high any individual item mounts so long as other economies resulting by its use equalise matters and maintain the desired condition of minimum output charges.

It is for just such reasons that gas is the ultimate fuel of industry. Gas makes possible improved processes in manufacture that may have little to do with the use of heat. Thus, to obtain straight-line production, so essential in mass production, a furnace must be a complete unit in itself, capable of exact control, to meet the time requirements of such a schedule. It must be accessible on all sides, and lanes cannot be left open for coal and ash haulage. The fuel must be adapted to the manufacturing process, not the process to the fuel. Power, labour, and quality of product are the determining factors in manufacture; and that fuel must be employed which permits their fullest realisation.

So far in the paper the effect and desirability of the fuel load to the gas industry has not been considered, and it should be of interest to touch briefly upon this point.

In the manufactured gas industry capital charges on the production and distribution equipment utilised are one of the principal factors in cost of product, the ratio of gross income to total investment being approximately 1 to 5. This low capital turnover makes the load factor of the various classes of business particularly important. An analysis recently made by one of the large manufactured gas companies gave the annual daily load factors for lighting as 49 per cent., for cooking as 74 per cent., water heating 56.7 per cent., hotel and restaurant 84 per cent., industrial 72 per cent., and house heating 28 per cent. It can be seen that the load factors of 84 and 72 per cent. respectively for hotel and restaurant, and the industrial loads makes this class of business very desirable from the gas company standpoint.

Continuity and increased production, the use of labour-saving machinery with unskilled labour in attendance, better working conditions, simplicity, quality production, and stability of fuel supply and prices, and how the manufacturer values fuels have been touched upon. These considered together make for increased production, better quality of product, and lower unit costs—three ideals for which every manufacturer strives.

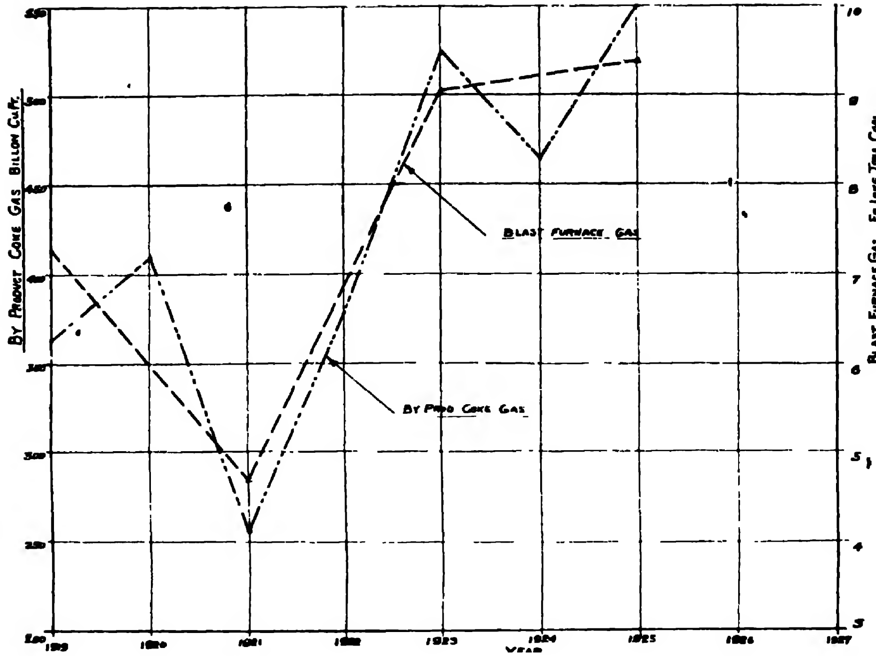
City gas has been shown to have all the advantages of other fuels without their disadvantages. It is fundamentally, economically and scientifically correct. No one can study the present

industrial tendencies without coming to the conclusion that its great advantages will carry more and more weight as the years go on, and that its use in industry will grow in ever-increasing amounts.

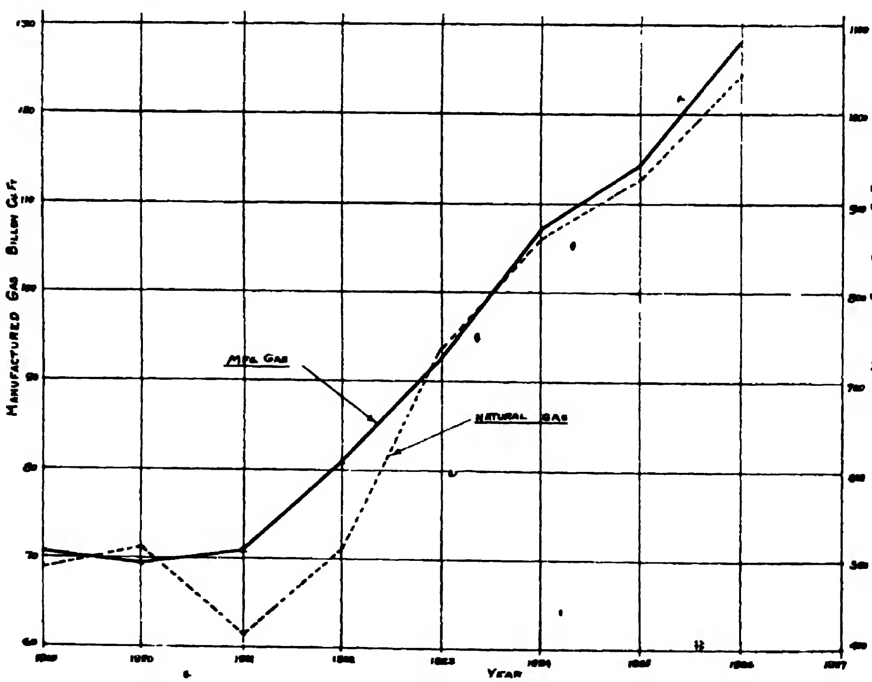
ZUSAMMENFASSUNG

Dieser Aufsatz behandelt Wachstum und Ziel der Gasverwendung in den Vereinigten Staaten. Daten und Statistiken werden angeführt, die zeigen, wie der Verkauf von natürlichem, fabriziertem, Koksofen- und Hochofen-Gas in den Jahren 1917 bis 1927 geschwankt hat. Die Entwickelung der modernen Wärmebehandlung als ein Schritt in dem fortwährenden Entwicklungs-Prozess ist dargetan durch Bilder und Daten. Einige der modernen Wärmeverfahren in der Stahl-Industrie, in der Wärmebehandlung von eisenhaltigen und nichteisenhaltigen Metallen, der Zubereitung von Nahrungsmitteln, der Herstellung von keramischen Waren und einer Reihe verschiedener anderer Prozesse, werden erläutert.

Die Vorteile, die den Aufstieg des Gases als Heizmaterial günstig beeinflusst haben, werden am Schluss des Aufsatzes angeführt.

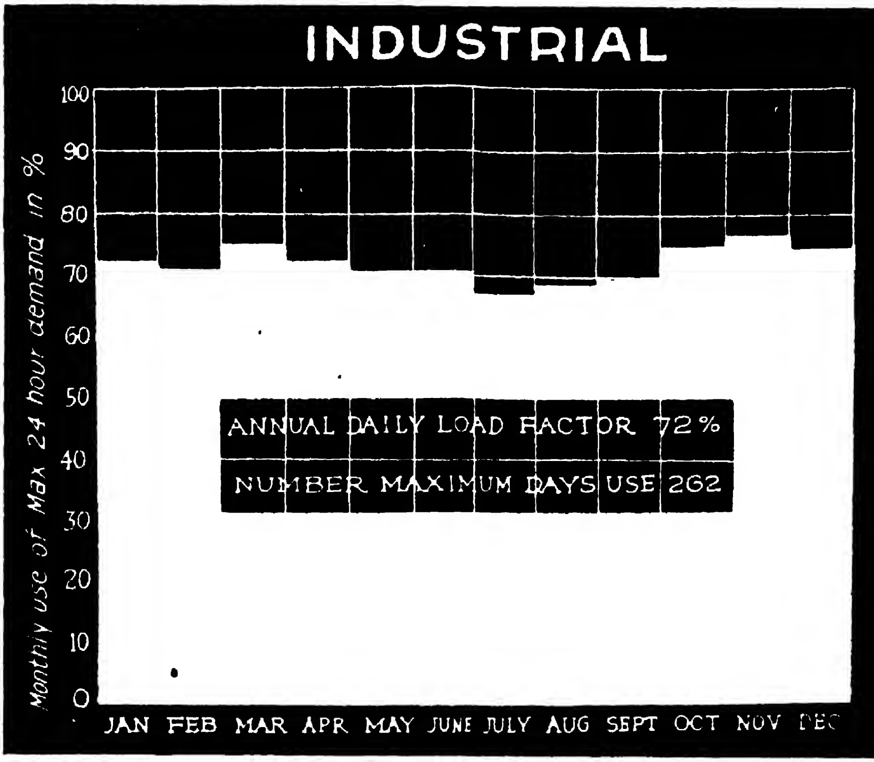


Curves showing the use of by-product coke oven gas for industrial furnace operations and blast furnace gas from 1919 to 1925, inclusive. The use of blast furnace gas shown in this chart is for driving engines, and boiler fuel. Approximately an equal quantity is used for heating industrial furnaces.



Curves showing the increase in the use of manufactured and natural gas for commercial and industrial purposes for the years 1919 to 1926, inclusive.

The increases in growth in the corresponding curves for by-product coke oven and blast-furnace gases do not show as large percentage increases as in the case of manufactured and natural gases.



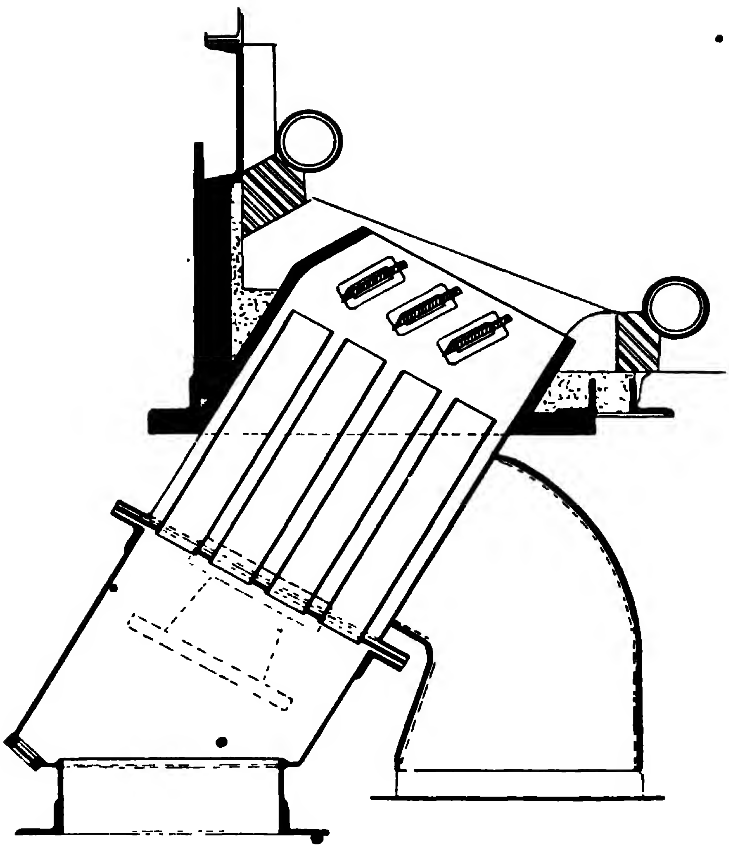
Typical load curve for a large manufactured gas company in the United States.

In this chart the whole rectangle may be taken to represent the capital required for the necessary production equipment to supply the maximum day of 100 The shaded portion below the curves may be taken to represent the annual daily load factor, or the amount of capital usefully employed.

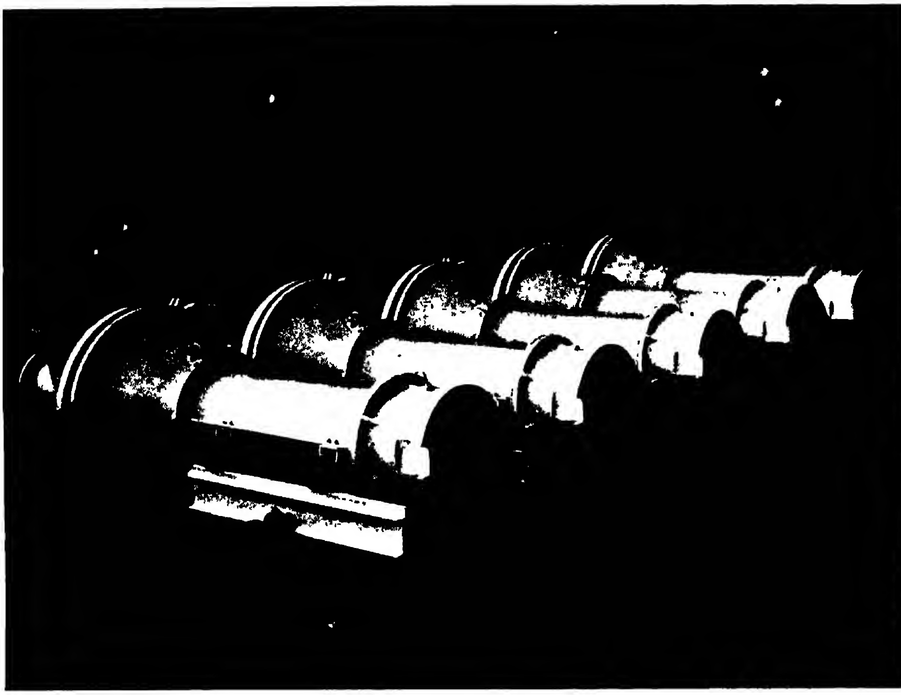
ILLUSTRATED APPENDIX

(Published by arrangement with
The American Gas Association)

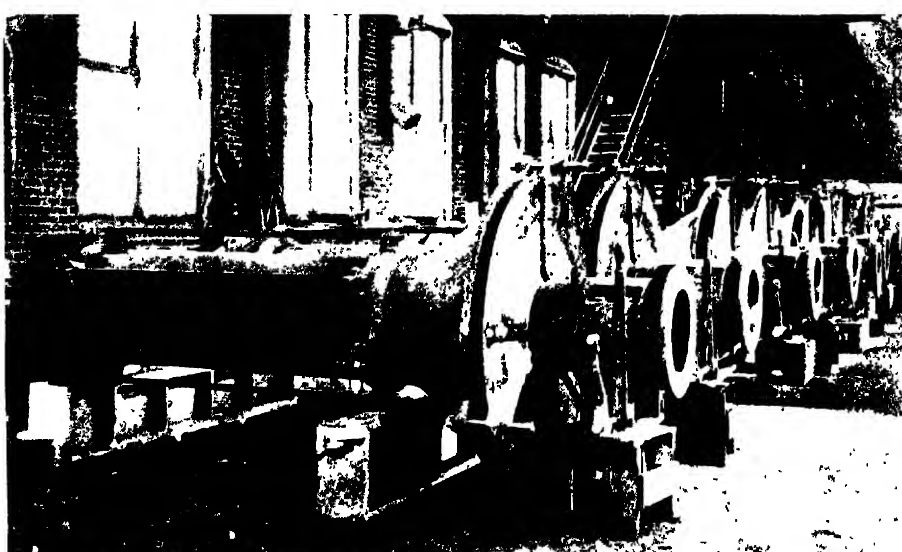
STEAM GENERATION



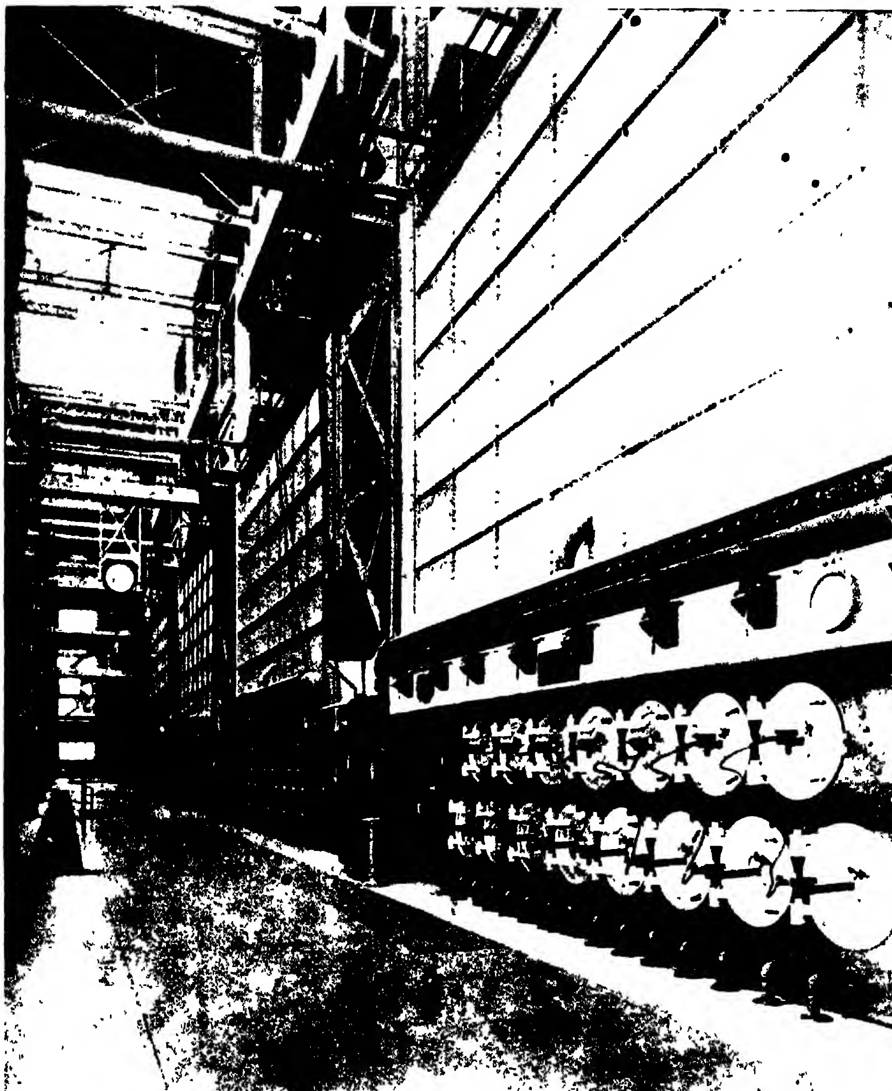
This cut shows the blast furnace gas burner used at the Ford Motor **Co.'s** plant at Fordson, Mich. These burners, four to a boiler, are made **by the** Combustion Engineering Co., and fire 24,000,000 B.Th.U. of gas per **burner** per hour.



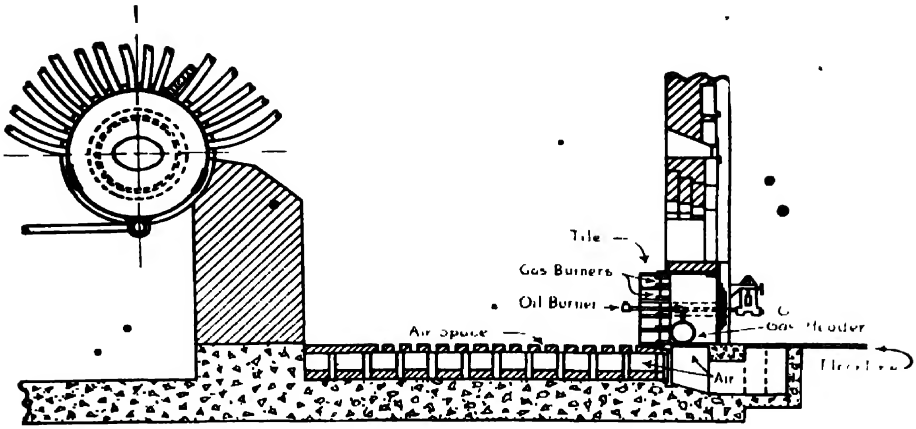
Burners used on hot stoves of blast furnaces for pre-heating the checker work of the stove. These burners are capable of vertical and horizontal adjustment, and have movable air shutters to compensate for the type of gas being used.



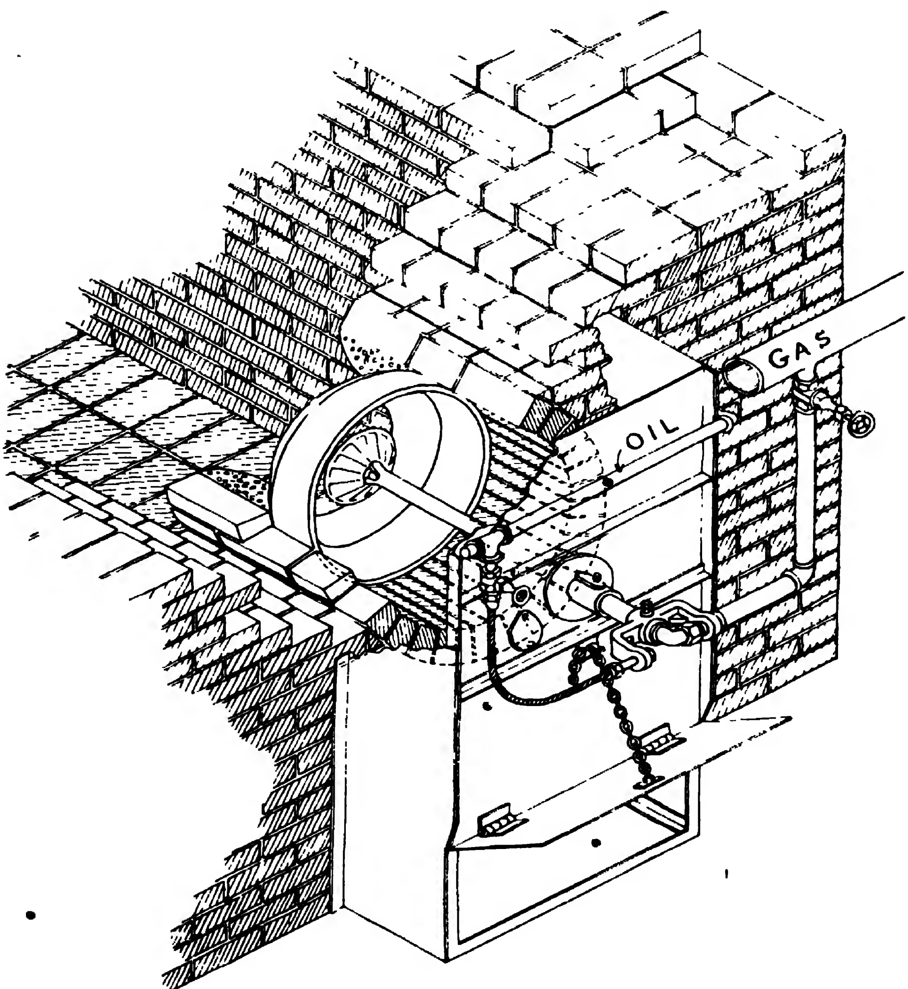
Battery of eight proportioning burners for use on two 1,200 H.P. boilers. Fuel used, 95 B.Th.U. blast-furnace gas. Capacity of these burners, 233,000 cu. ft. per hour each.



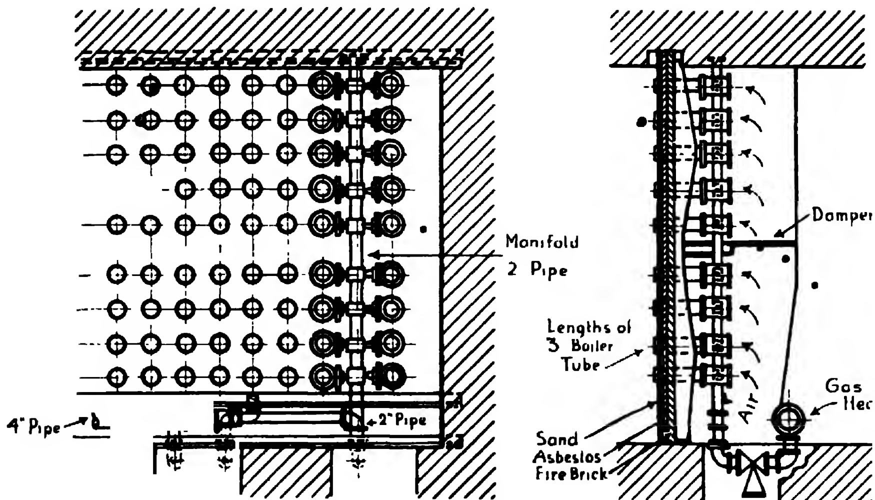
Boiler room at Long Beach No. 2 Station of the Southern California Edison Co., Connelly boilers, Stirling type, 15,000 sq. ft. surface, equipped with fifteen Peabody combination oil and natural gas burners. Stone & Webster, Inc., Engineers.



Improved arrangement of natural gas low-pressure burners at Los Angeles Gas & Electric Co.

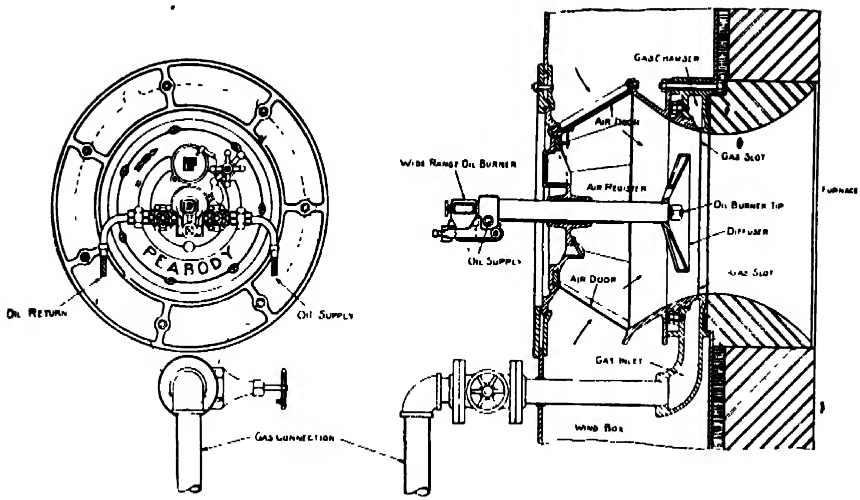


Forney combination oil and gas burner for boiler use, as largely used in the Texas-Louisiana field It may be used with natural or forced draft.

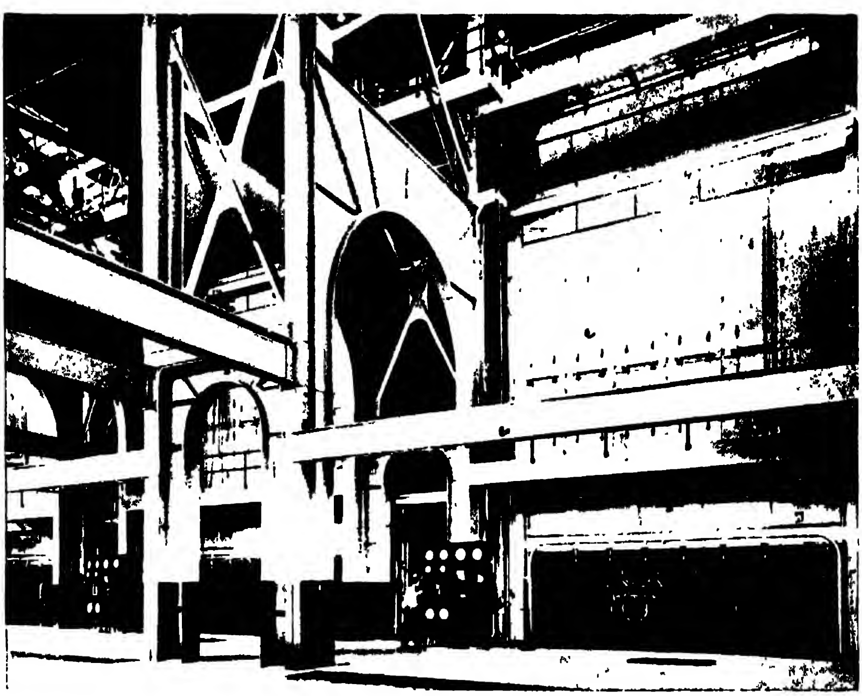


Low-pressure natural gas burners, as applied in the Los Angeles Gas and Electric Co.'s old station.

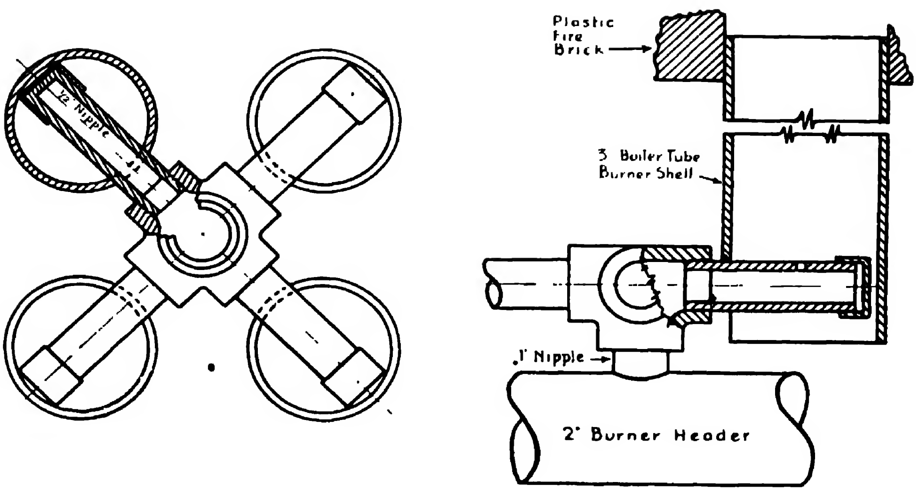
Dallas Power & Light Co. high-pressure gas burner, installed in 1,700 H.P. B. and W. boiler with San Diego mechanical oil burner. Dallas, Texas, May 7, 1924.



Peabody combination oil and gas burner, used in large installations. These burners will fire upward of 50,000 cu ft. of natural gas per hour at very good efficiency.

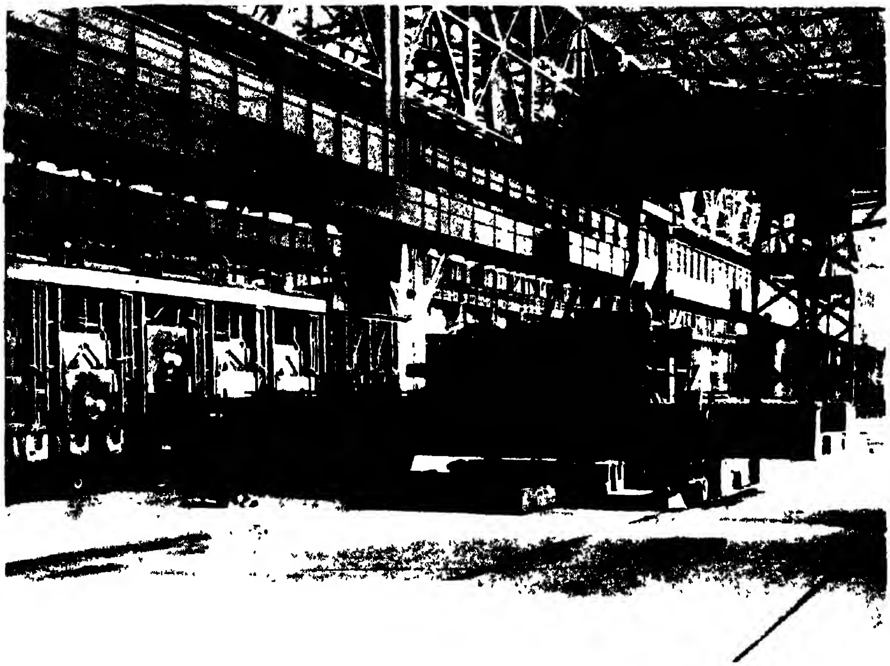


Boiler room at the Seal Beach Station of Los Angeles Gas & Electric Co., Babcock & Wilcox cross-drum boilers, 25,450 sq. ft. surface, equipped with fourteen Peabody combination oil and natural gas burners. Dwight P. Robinson & Co., Engineers.



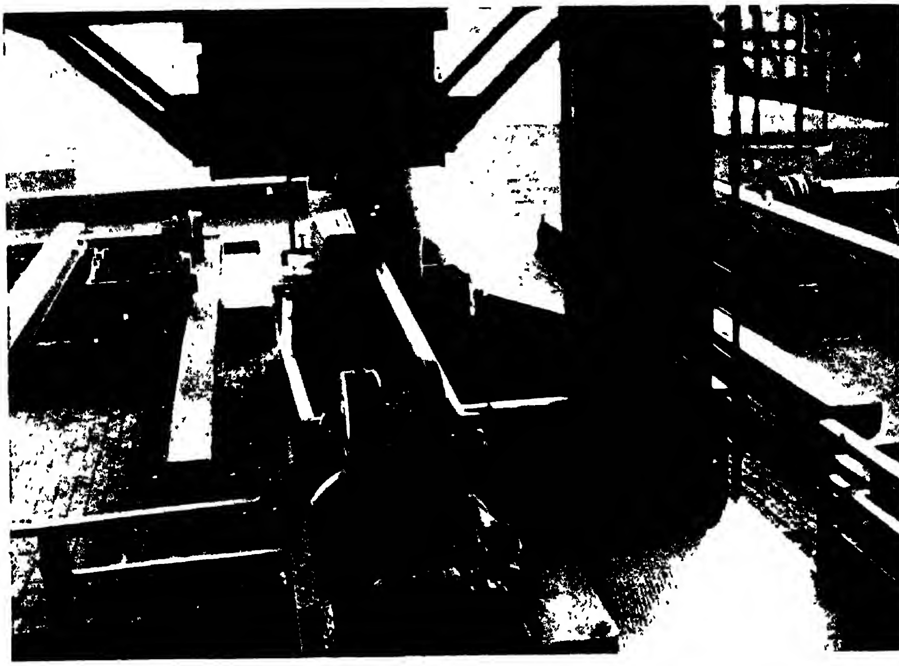
Detail of low-pressure natural gas burner, Los Angeles Gas & Electric Co.

THE STEEL PLANT



Open hearth gas-fired steel furnaces (Fordson Plant, Ford Motor Company), showing charging floor and charger

General view of gas-fired open hearth steel plant, showing pouring floor. Fordson plant of the Ford Motor Company.



Soaking pits, gas-fired, for equalising heat in steel n prio to the break-down Ford Motor Company

BILLET RE-HEATING FURNACE

Photograph shows six high-pressure gas burners on an operating platform level. This furnace has a capacity for heating 85 tons per hour of steel billets, fed partly hot.

The discharge end shown below the platform lever and the roll conveyor leads the billets to the mills for breakdown.

SHEET FURNACES

Double chamber furnaces for heating nickel, monel metal and steel sheets preparatory to rolling into lighter gauge sheet metal

A furnace of this type produces approximately two tons of finished sheets per hour at a gas consumption of about 1,100 cu. ft. of 1,000 B.Th.U. natural gas

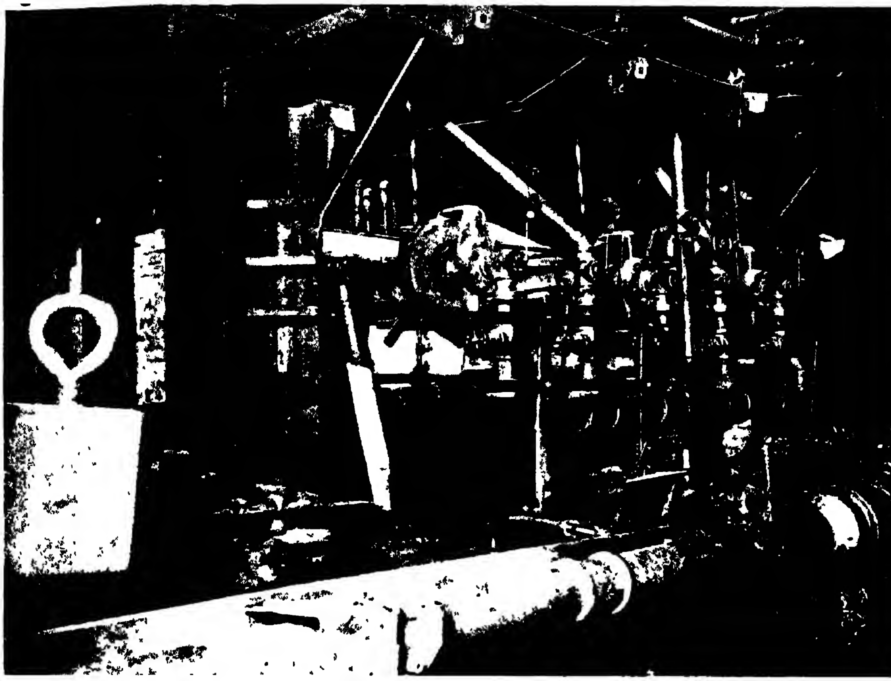
Three-compartment pair heating furnace for heating nickel, monel metal or steel slabs in pairs for breaking-down for sheet rolling. The pairs are heated to a temperature between 2060°F. and 2100°F., with a heating time from room temperature to working temperature in a maximum of 12 hours.

A furnace of this type has a production of approximately 1 ton per hour, with a fuel consumption of about 2,400 cu. ft. of natural gas of 900 B.Th.U.

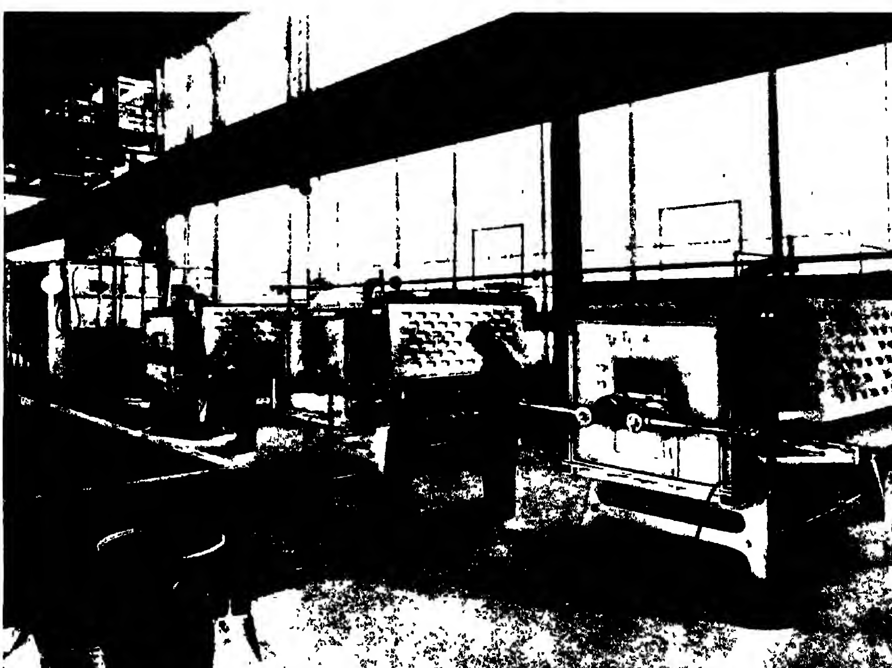
OPEN ANNEALING FURNACE

Open sheet-annealing furnace, for individual annealing of steel, nickel, or monel metal sheets. These furnaces are approximately 70 ft. long 6 ft. wide, and have a capacity up to 150 tons per 24 hours. The gas consumption when operating at this rate is approximately 2,800 cu. ft. of 950 B.Th.U. natural gas per ton

The roll mechanism is so delicate and accurate that the sheets come out two a minute with no surface disfigurations. They are then ready to be finished by the application of two layers of spray lacquer.

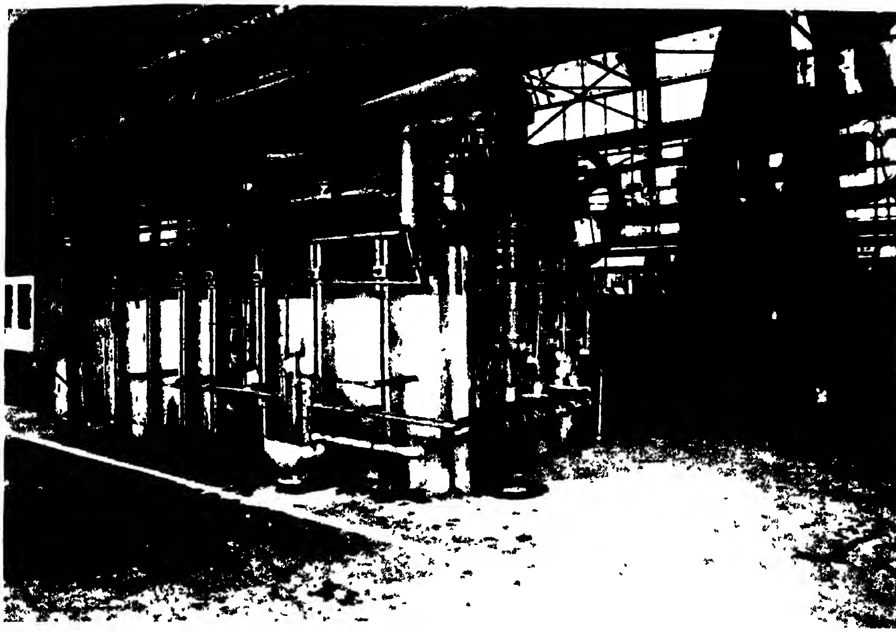


Piercing Mill
High-pressure gas burners at the outlet end of the piercing mill for heating steel billets before piercing in roller bearing races.



High-pressure coke oven gas-fired forges, for heating steel to be forged. Ford Motor Company.

HEAT TREATMENT OF FERROUS METALS



CONTINUOUS FORGE FURNACE

Forge furnace shown on the left is in reality a small pusher billet furnace. Burners are located near the outlet end and fire counter-current to the direction of the work. The door for removing the finished work is on the other side of the photograph, directly in front of the forge

Crank shafts can be forged, using natural gas at $50 per M. cu ft, at a saving of approximately 45 per cent. over oil-fired batch type furnaces.

ROD HEATING SURFACE

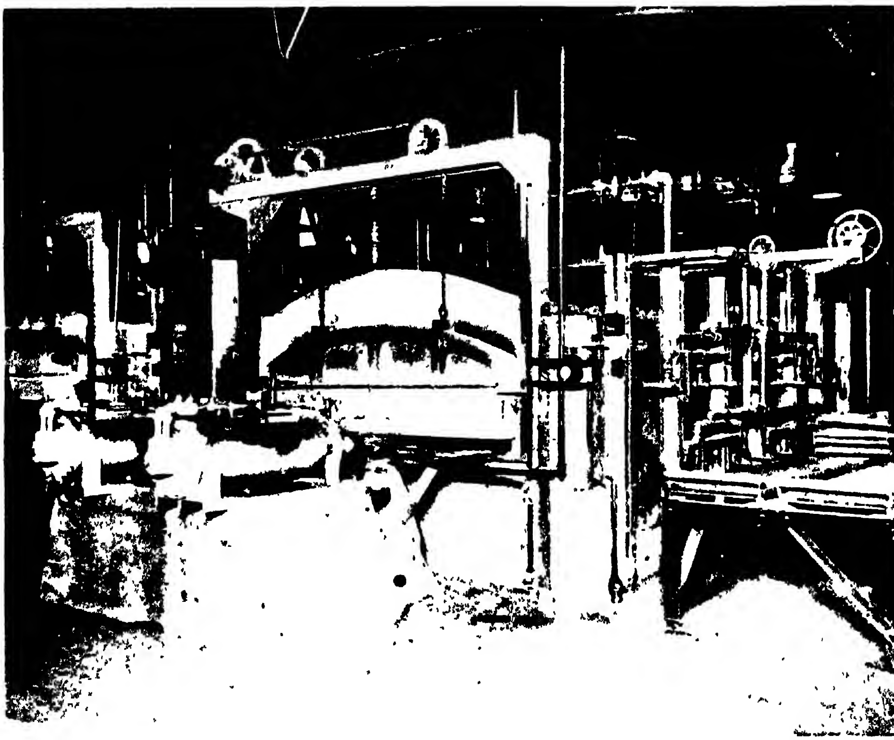
These furnaces operate on natural gas, continuously heating rods to be cut-off and upset into bolts.

Rotary carbonising machines with a capacity of 1,000 to 1,200 lb. metal.
The charge to be carbonised is introduced and after two hours the temperature of the charge is at the desired point of 1,650°F. The gas consumption during this time is 400 cu. ft. of 1,000 B.Th.U. natural gas per hour. While the temperature is being maintained, a gas consumption of 200 cu. ft. per hour is used.

ROTARY CARBONISING MACHINE

Battery of rotary carbonising machines for conveyor belt links With a gas cost of $0.87 per cu. ft. of 525 B Th.U. gas, the cost for a 500 lb charge is as follows:—

Gas	$1·651
Compound	0.295
Labour	1·700
Quench oil	0·218
Machine expense	1 600
Overhead factor . . .	40 per cent



CONTINUOUS CARBONISING FURNACE

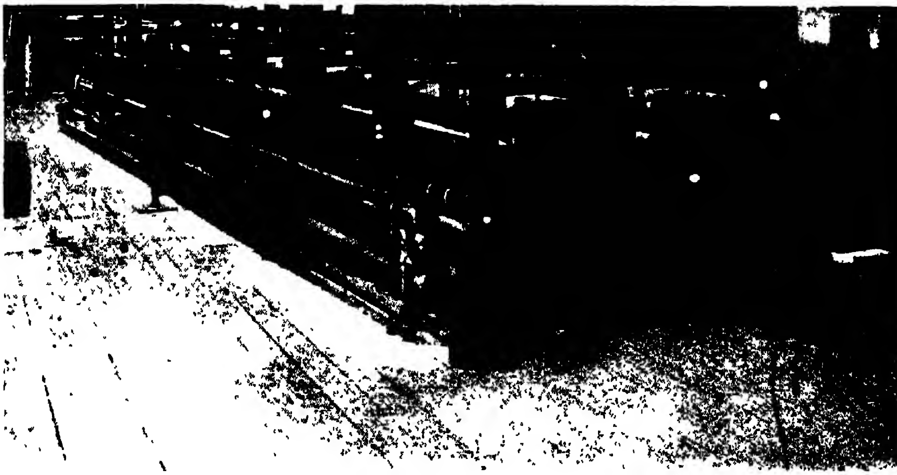
Box type carbonising furnaces for carbonising automobile crankshafts, gears, and parts. The parts to be carbonised are packed in carbonising boxes and pushed through the furnace in an inverted position resting on the box cover.

The use of a continuous furnace of this type has reduced the labour cost approximately 65 per cent. and made other savings possible, amounting to an annual saving on the completed installation of 68 per cent.

WIRE PATENTING FURNACE

Patented or open annealed wire is heated in an oven furnace to between 1700° and 1800°. The patenting furnaces are 50 ft. long with a solid hearth 48 in. wide inside The burners are distributed along the side walls of the hearth, and when patenting 1,200 lb. of wire per hour, the gas consumption is approximately 1,800 cu. ft.

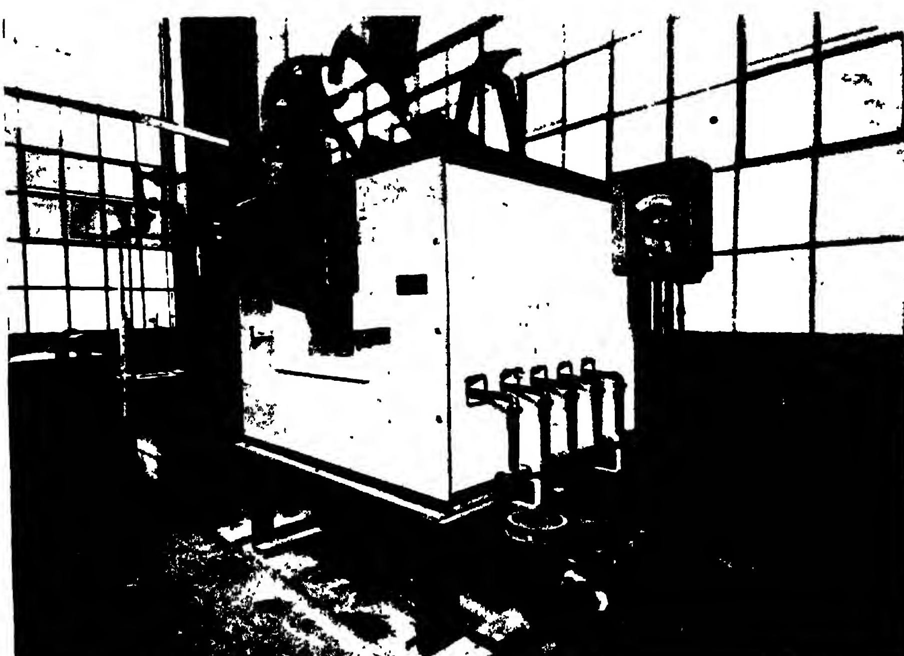
The temperature and furnace atmosphere produce an even wire which has the same grain structure and the same physical qualities that were previously obtained by pot annealing in an 18 to 24 hour cycle.



COMBINATION WIRE HARDENING AND ANNEALING OVEN

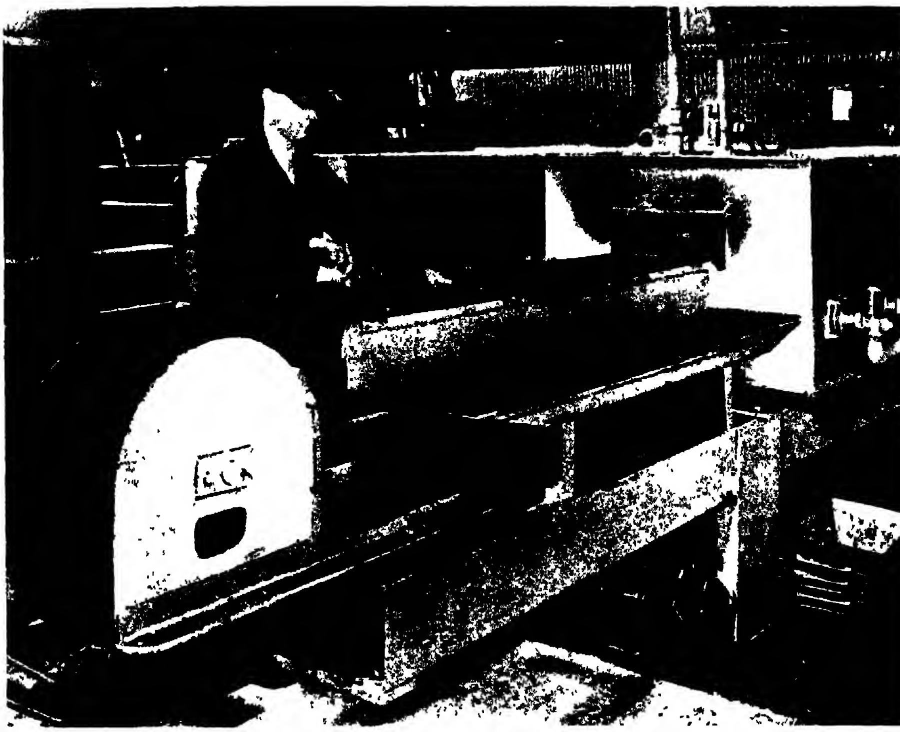
Wire is hardened a d annealed in continuous lead baths in which the temperature is automatic lly ontrolled These furnaces, of which there are two, have a combined p oduction of 3,000 lb. of $\frac{3}{8}$ in diameter wire per hour.

The gas consumpt on for hardening and annealing is at the rate of 2·05 cu ft. per lb of finished v



HEAT TREATING FURNACE

This furnace is used for heating magnets, the production being 1,080 lb. per day, metal being heated to a temperature of 1,600°F. The cost of operation at \$·85 per M. of 540 B Th U. gas is \$·00260 per pound.

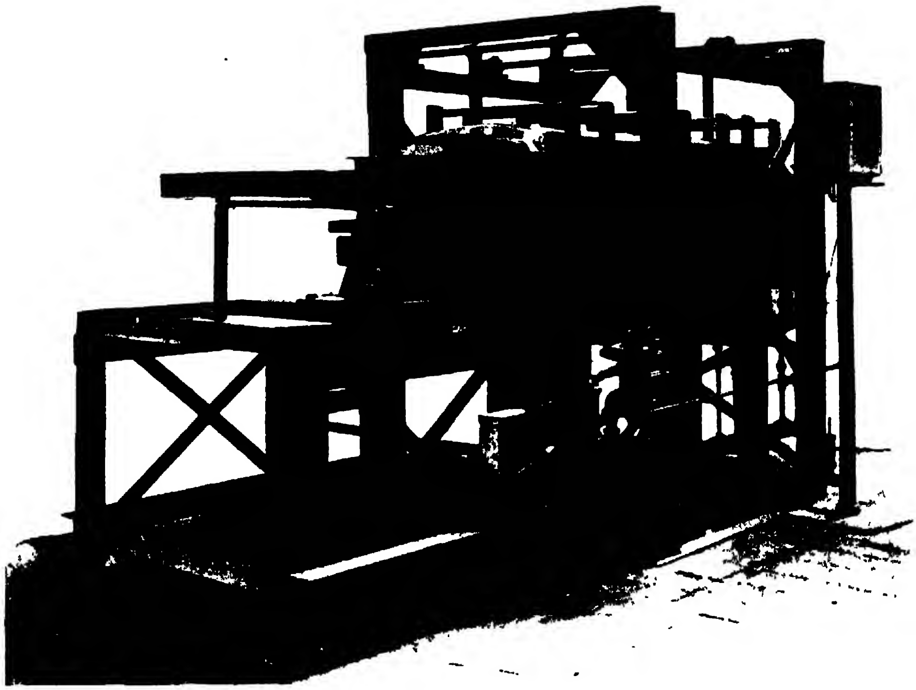


CONTINUOUS HEAT-TREATING FURNACE

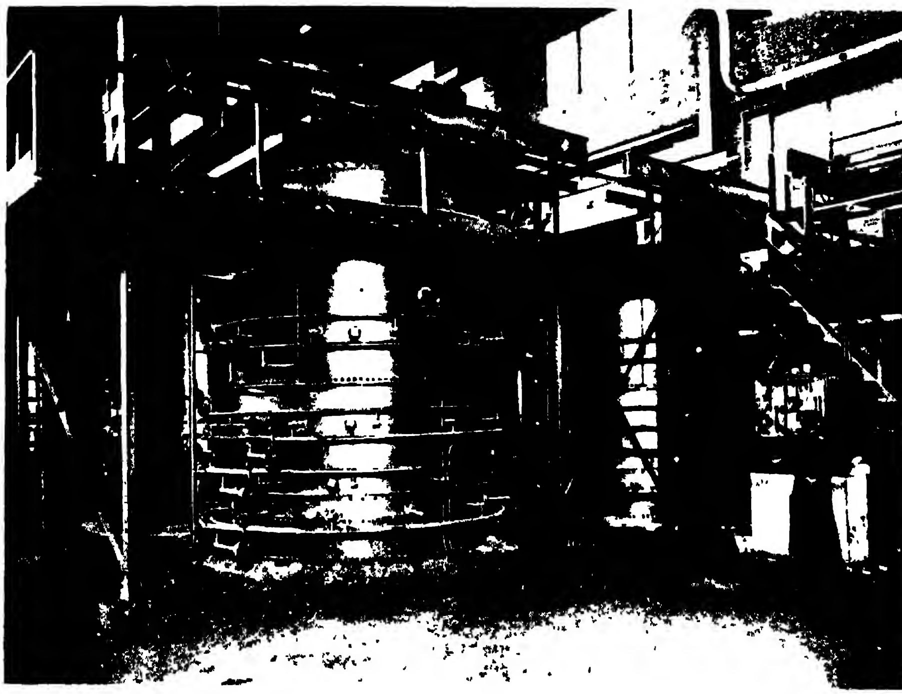
Heating-treating furnaces of the conveyor belt type, in which small parts to be heat treated are loaded directly on the heat-resisting alloy hearth, pass through the heating zone and discharge into the quenching tank. These furnaces can be arranged in series so that the work can be delivered directly from the quenching tank to the annealing furnace for the next operation.

Furnaces are automatically controlled, both as to temperature and furnace atmosphere. When heat treating cap screws, from 12 to 16 minutes are required for the work to pass through the hardening furnace, the temperature being at 1,550°.

All work being heated in this type furnace is subject to the same conditions so that uniformity of product is assured. One furnace operator can feed three furnaces.

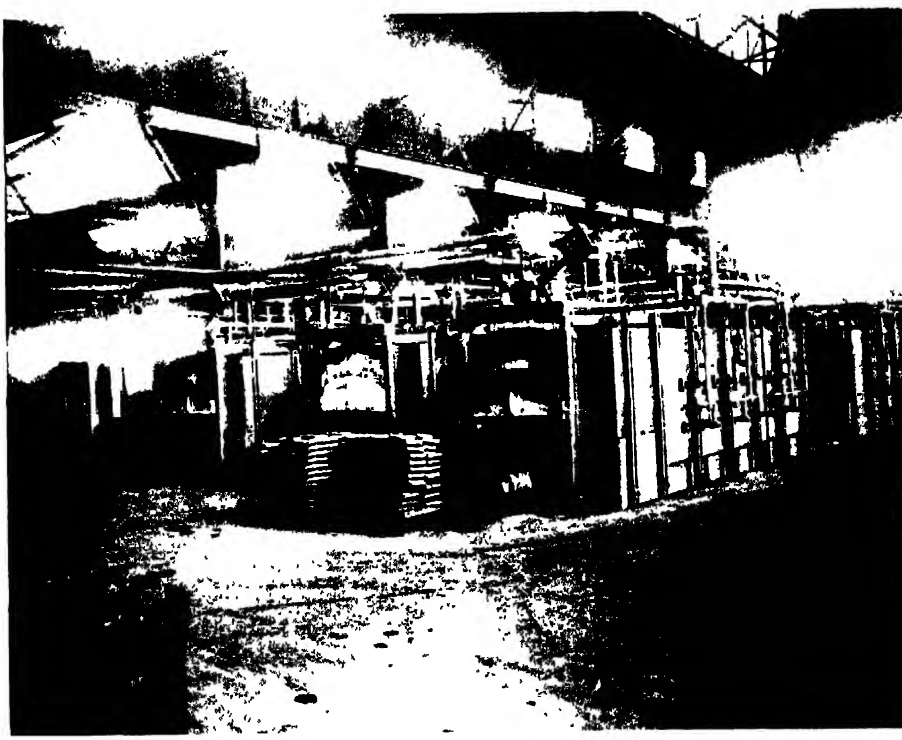


Reciprocating hearth type of hardening furnace for heat-treating ball-bearing races. The hearth of these furnaces is moved forward and stopped suddenly. Work on the hearth travels by the inertia when the hearth is suddenly stopped. 260 lb. per hour of ball bearings is the maximum capacity. During a test period of 59½ operating days, the actual capacity obtained was less than half of this because of the amount of work available. The unit cost, including depreciation, interest, floor space, maintenance and operating costs, are $·79 per 100 lb. of material produced.

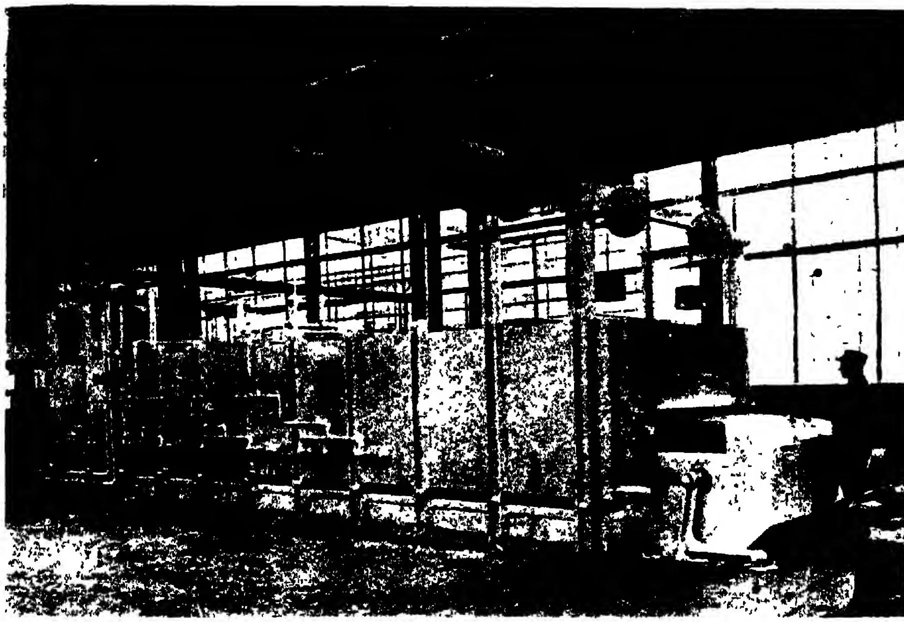


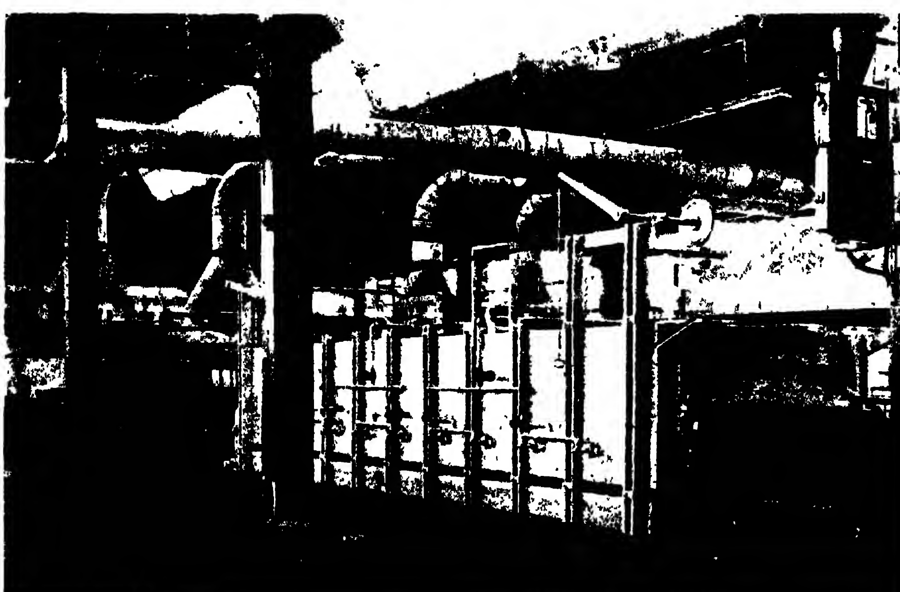
VERTICAL FURNACE FOR HEAT-TREATING CANNON

Cannon to be heat treated are directed into the furnace by an overhead crane. By tangential firing a uniform temperature is achieved throughout the heat-treating operation and throughout the entire furnace chamber. The cannon to be hardened are heated at the rate of 200° to 300° per hour until a temperature of 1650° is reached. They are then soaked for 5 hours at this temperature and quenched. The average time for heating is approximately 10 hours. In a week's period, following this cycle, approximately 180,000 lb of metal were treated at a gas consumption of 512,000 cu ft.



Battery of heat-treating furnaces in automobile plant
The four batteries of furnaces shown are part of a group of thirty-two continuous furnaces for hardening and annealing automobile parts.

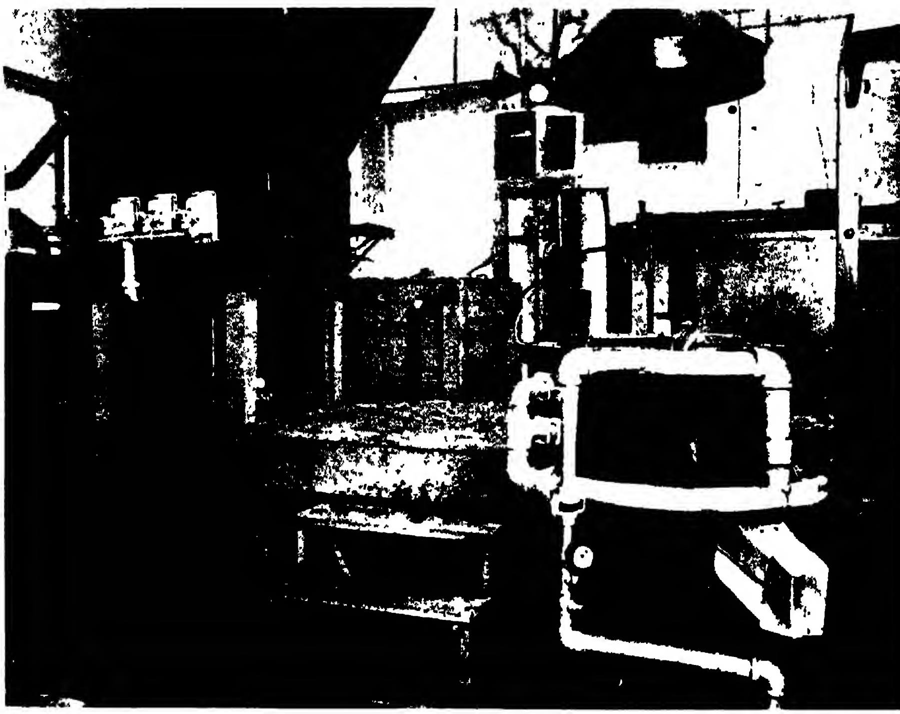




HARDENING FURNACE

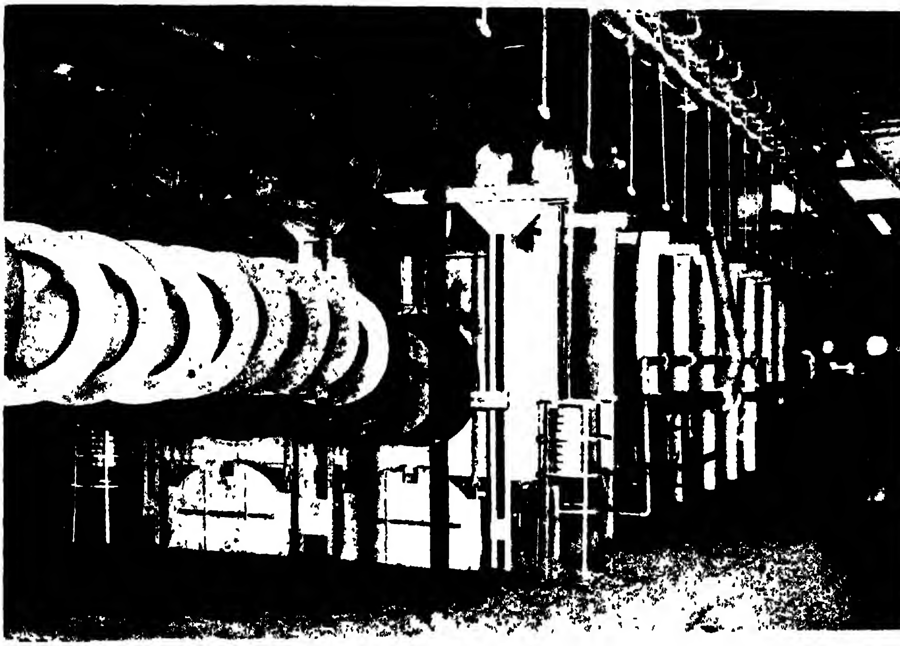
Spring hardening furnace at an automobile plant for hardening and drawing spring leaves. The spring leaves are hardened and subsequently assembled in the completed automobile spring. They are hardened individually on a travelling conveyor.

The furnaces are arranged in series so that after hardening and quenching they can be drawn without unnecessary labour in handling.



HEAT-TREATING SHOP

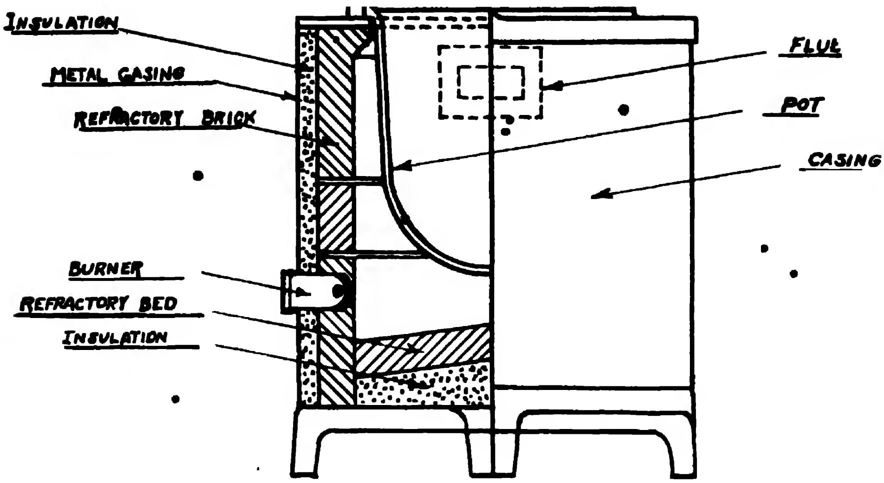
Small heat-treating shop for doing job work in a metropolitan city. An oven furnace and a cyanide furnace are shown. In addition to these furnaces, there are also installed in this shop a drawing furnace and a lead bath.



Furnace for annealing deep-drawn copper or steel stampings.

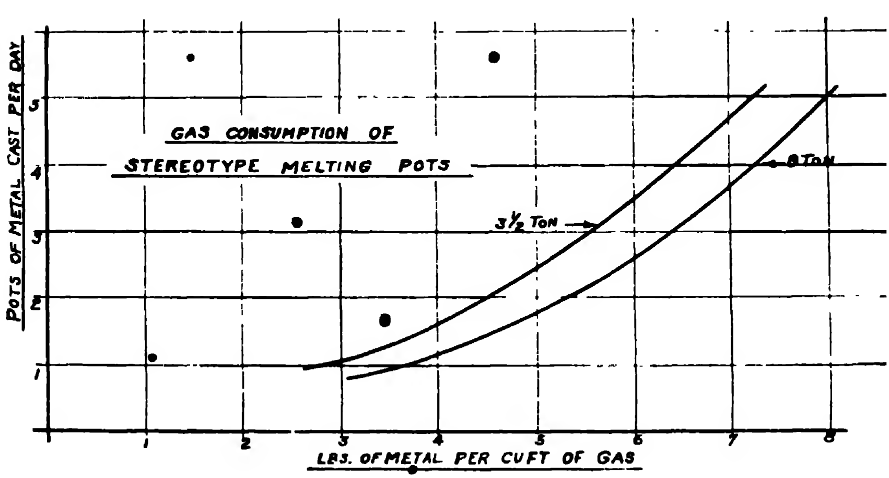
The blueing of the barrels and other parts of rifles by the Winchester Repeating Arms Co. is accomplished in gas-fired furnaces, of which there are forty-eight. These consist of a rotating drum within a shell, the burners firing in the space between the two. The drum is filled with charcoal and retort pine tar into which the parts are thrust

HEAT TREATMENT OF NON-FERROUS METALS

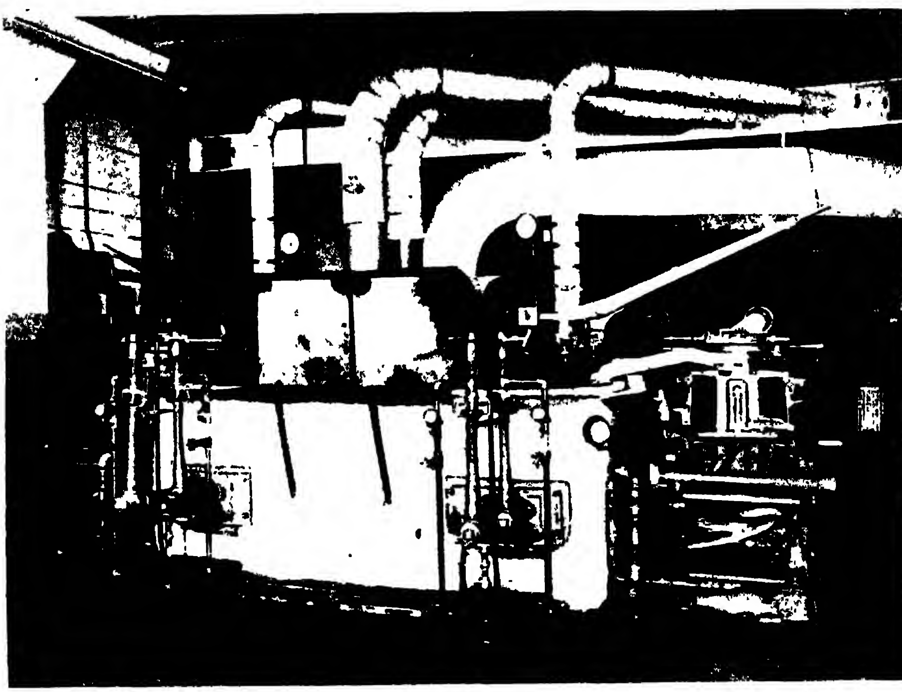


SOFT METAL MELTING POT

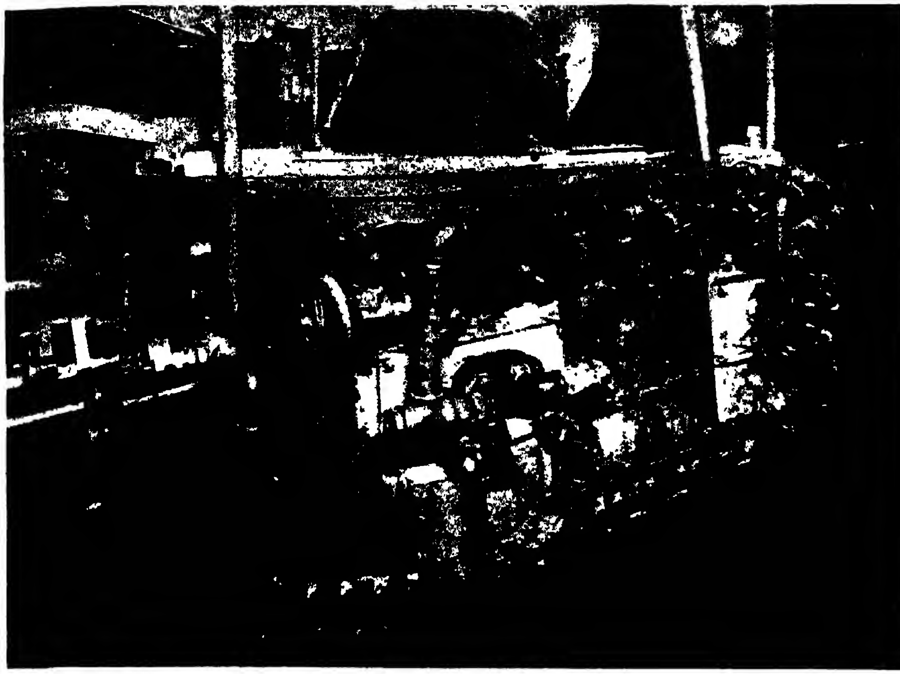
The cross-section of the pot shows the construction of this furnace using fire-brick linings, diatomaceous earth insulation, and the metal casing. The bottom of the furnace is inclined to a drain hole to drain any metal which would fall into the combustion chamber, because of pot failure. Burners in soft metal melting work are always located below the bottom of the pot with the flue at the top. Furnaces of this type can be obtained mounted on a tilting thrown to eliminate the hand labour of ladling contents of the pot.

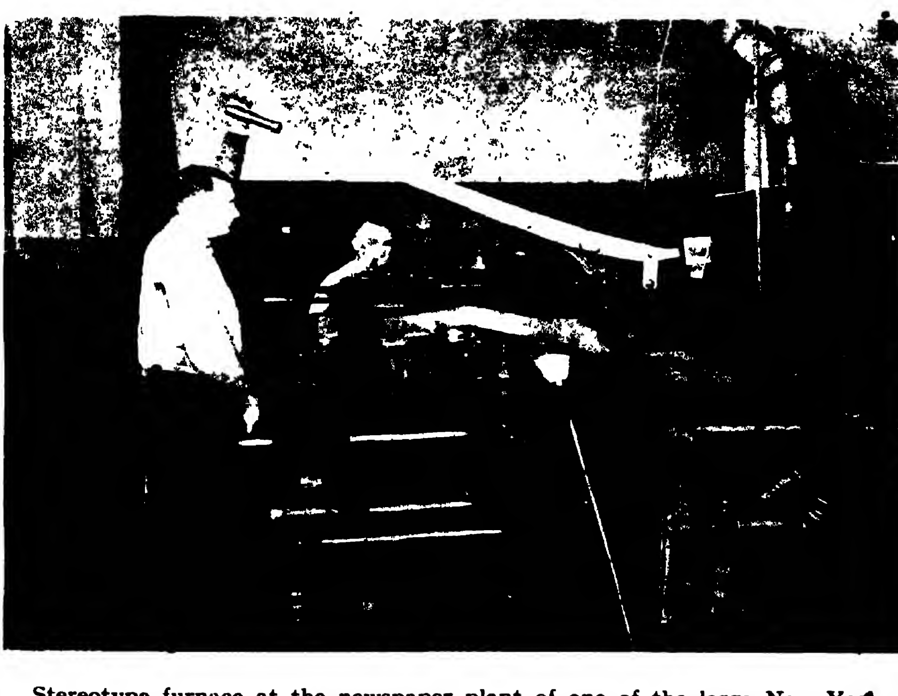


One of the largest outlets for gas is in the melting of newspaper metal. The curve which was drawn shows the amount of metal melted per cu. ft. of 540 B.Th.U. gas for various rates of operation of stereotype pots. These stereotype pots are insulated with at least 3 in. of effective insulation and controlled by thermostatic control. Although this curve is a theoretical curve on the basis of the radiation losses and theoretical heating requirements for melting, the actual results of a number of installations agree very closely with the curves which have been drawn.



STEREOTYPE POT
Automatically controlled and heavily insulated stereotype pot for maintaining accurately the temperature of the stereotype metal.



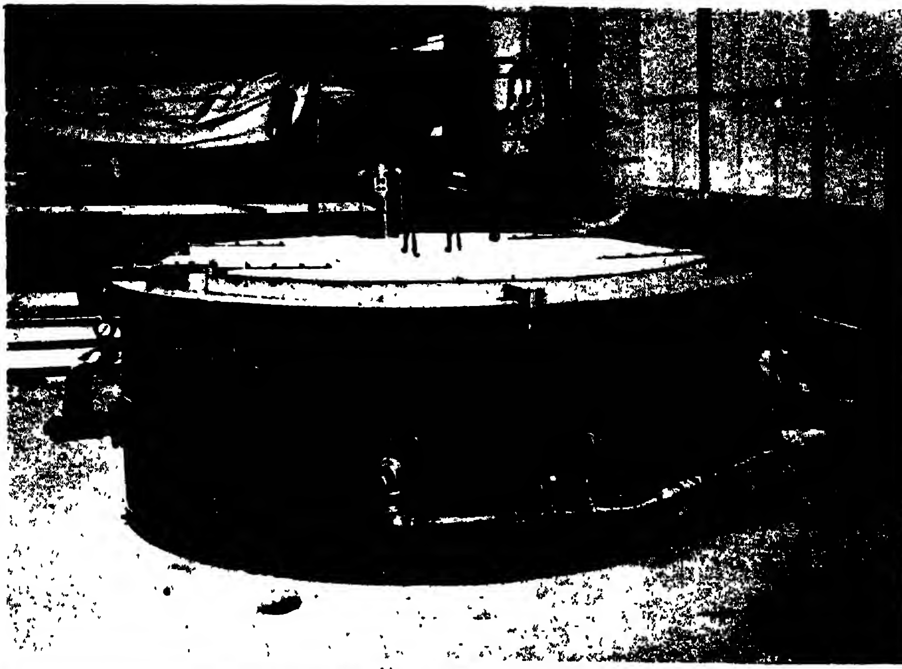


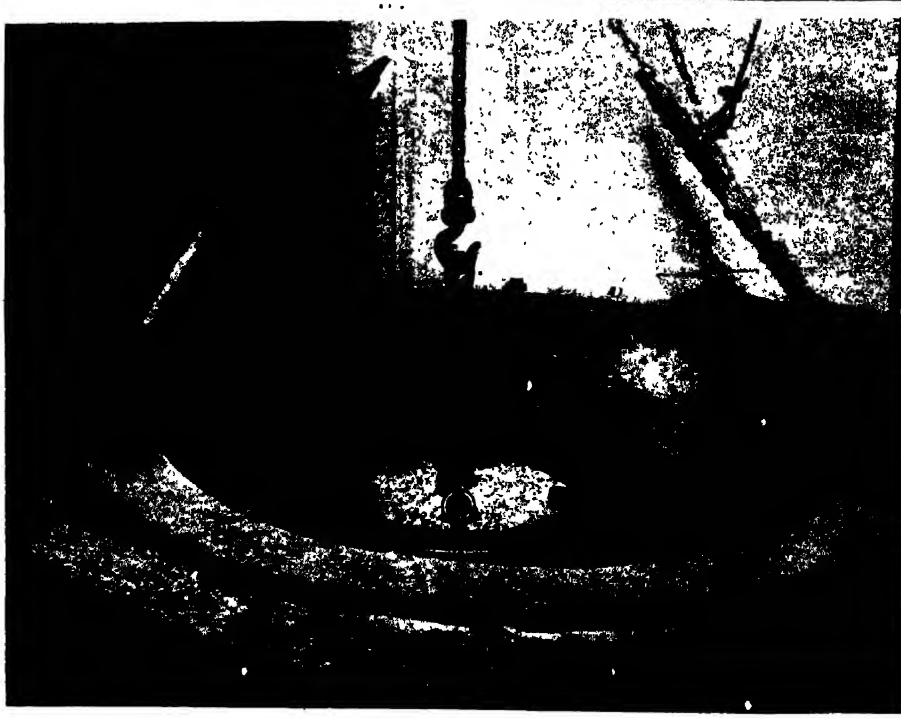
Stereotype furnace at the newspaper plant of one of the large New York metropolitan dailies
The gas consumption of these furnaces when insulated and with automatic temperature control, is given in the chart of gas consumptions.

SOFT METAL FURNACE
Furnace for melting linotype slugs in printing establishment.

Electrotype melting furnaces in a large magazine publishing house.
The two pots shown are bottom draw-off kettles, the metal being drawn off in the ladles and then used to back up the electrotypes shown in the front table.

SOFT METAL FURNACES
Furnaces for melting bearings for railway rails.
Two furnaces are operated, one being used for melting, while the other is being used for pouring moulds





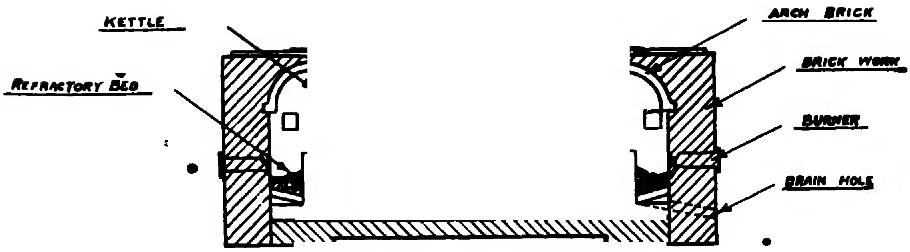
SOFT METAL FURNACES

Furnace used for heating tyre moulds. The tyre mould is lowered into the lead bath at a temperature of approximately 800°F. before vulcanising the rubber tyres.

Casting Lead Ingots
The lead pots shown in the background are in duplicate, one pot being used for melting while the other is being used for casting ingots The ingot moulds are water-cooled to chill the metal as quickly as possible

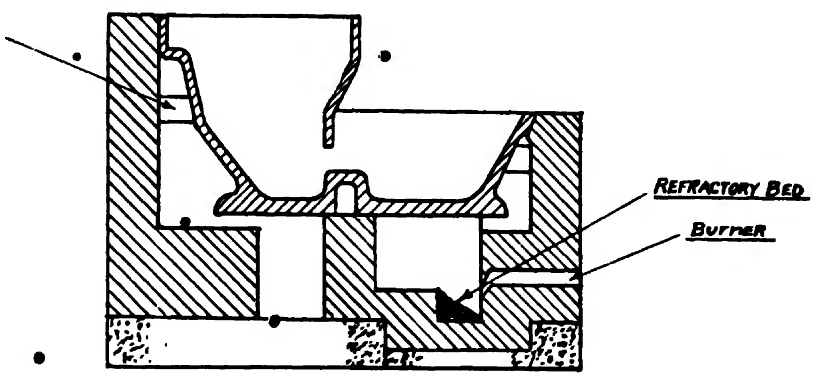
Battery of Recuperative Brass Melting Furnaces
Furnace for melting brass for meter parts, show an overall saving with gas at $·70 per M. cu. ft. of 540 B.Th.U. gas, against coal at $20·00 per ton delivered on the foundry floor, of $2·54 per cwt. of metal mounted.

ROTARY RETORT BRASS MELTER
Production, 200 lb. per hour Fuel consumption, approximately 2 cu. 540 B.Th.U. gas per lb. of brass melting.



GALVANISING KETTLE

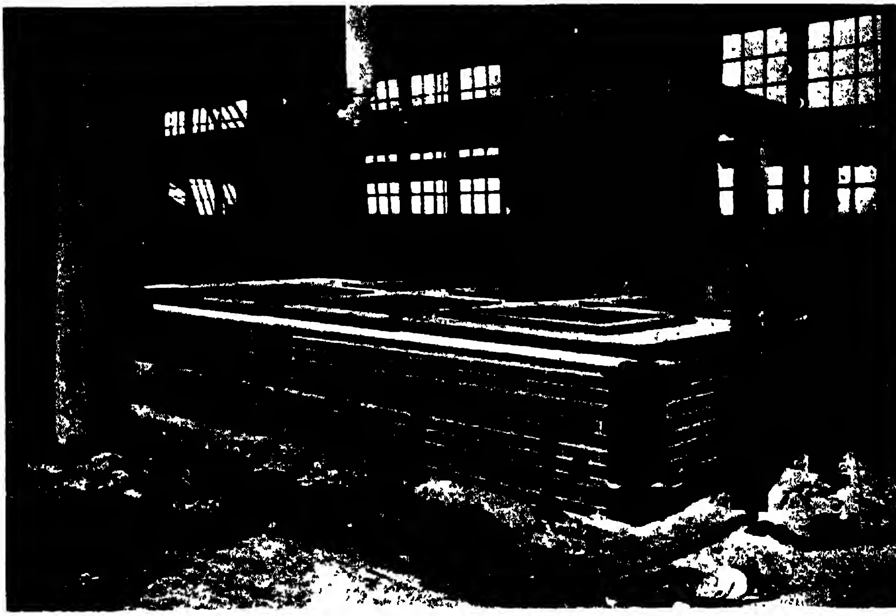
This setting shows a galvanising kettle of heavy fire-box steel which rests on the fire-brick floor. Heat is supplied along the sides of the kettle by means of refractory-fed burners. The dross, being heavier than the metal, sinks to the bottom. Heat is prevented from passing through this mass of dross, which would burn out the kettle, by means of fire-brick baffles placed in front of the burners The radiant heat is reflected from the walls of the setting through the sides of the kettle above the dross line. These kettles are supplied with conveying mechanism for tipping the large steel sheets under the surface of the zinc, and after coating, passing the sheets on to a travelling conveyor for moulding.

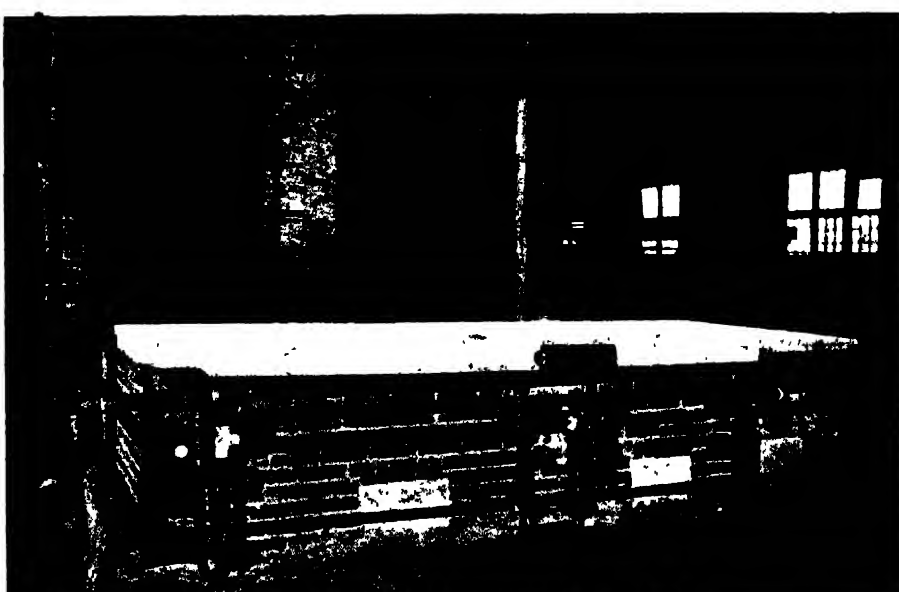


TIN MELTING POT

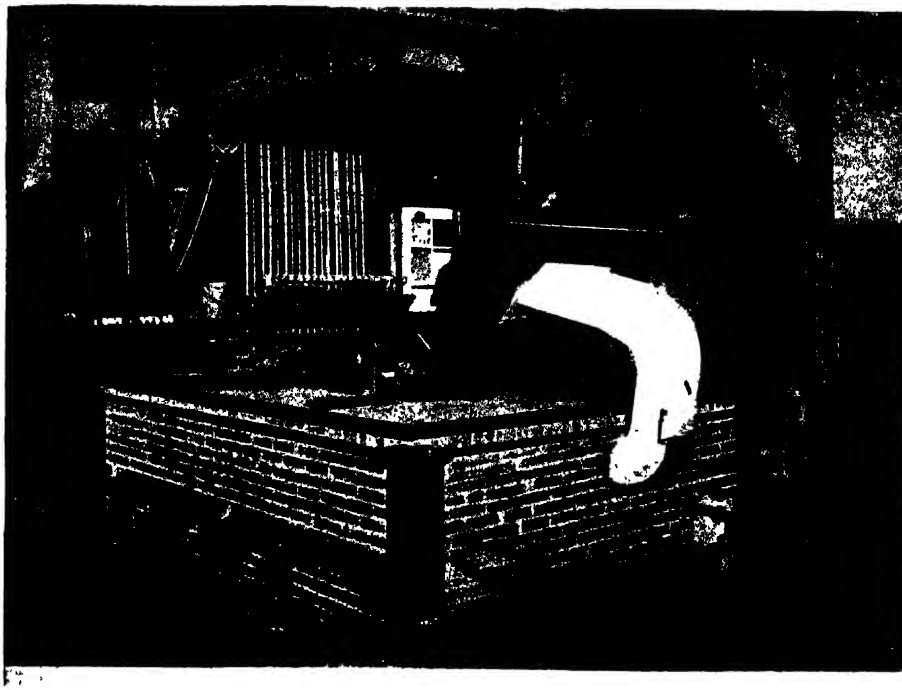
TIN MELTING POT

The tin melting pot is made in two halves, the inlet side being lower than the outlet side, it is fed either by hand or by a newly-developed feeder, the sheet steel being guided through by means of revolving rolls and issuing from the tinning pot fully tinned on the outlet side. The temperature of the tinning pot is maintained very exactly to prevent flashing of the oil flux which is used, and to produce a very uniform coating of tin over the sheet steel. After leaving the tin bath the tin plate is swept with ground peanut shells and then polished and dried by means of soft bristle-revolving brushes.





Duplicate set of tinning baths in one setting. These baths include the list pot, the tallow pot and the tinning pot. They are fired by high-pressure gas. The cost per ton of metal tinned, with fuel at $·90 per M. cu. ft. of 540 B.Th.U. gas, varies between $1·30 and $1·45 per ton.

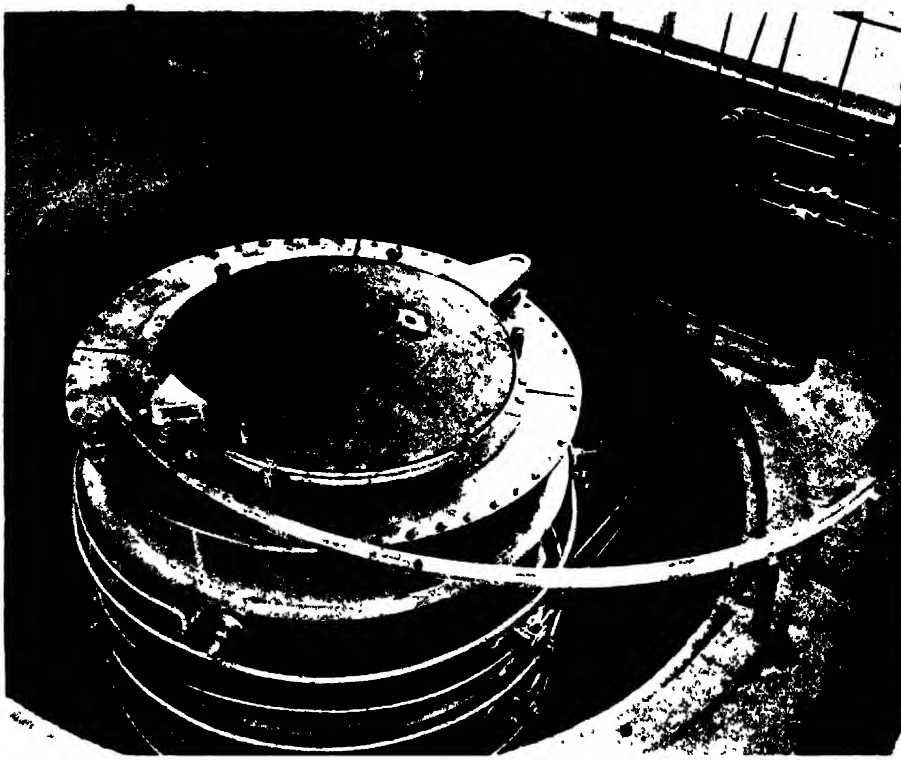


Strip galvanising kettle for galvanising steel strips.
Production of this pot during a continuous run of 51½ hours was 38,186 lb. with a gas consumption during galvanising of 1·2 cu. ft. per lb. of wire.

Galvanising tank for galvanising range boilers.

Dip galvanising kettle for galvanising metallic caskets and steel boxes. The application of fuel for this galvanising pot follows exactly the drawing of the continuous galvanising kettle.

BRIGHT ANNEALING FURNACE FOR NICKEL SILVER
A pusher type furnace for annealing nickel silver knife and fork blanks before stamping.
The view shows the air-tight inclined hood, and the quench tank for quenching before removing.



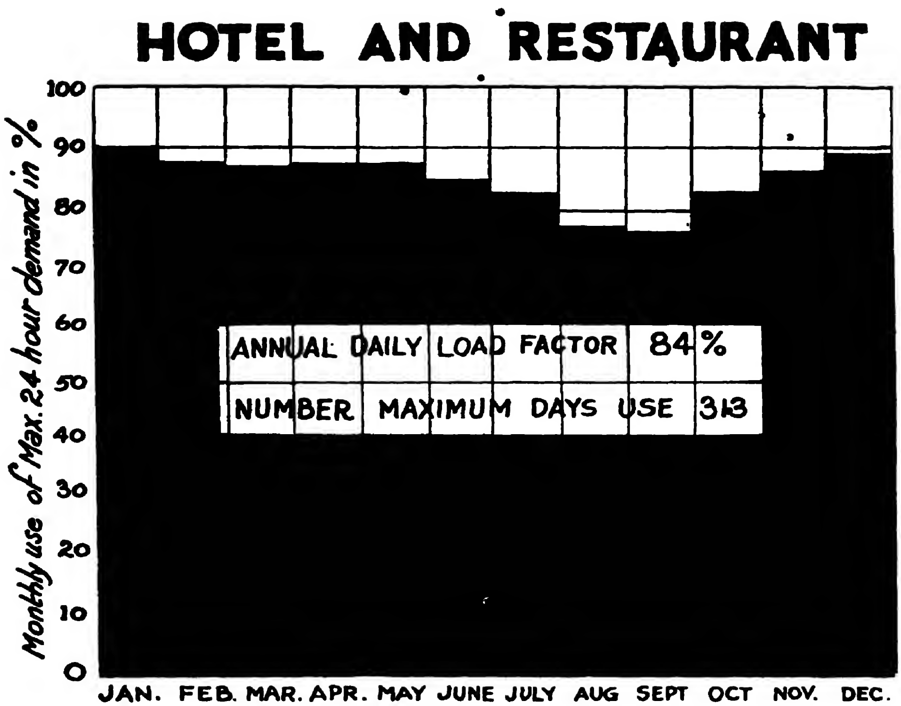
ANNEALING FURNACE
Brass tubes, which are later crimped into bellows, are annealed between deep drawings.

An overall fuel consumption of approximately 1 cu. ft. of gross metal, which includes the weight of the supporting baskets, was obtained.

RETORT ANNEALING FURNACE
For annealing small brass shells before deep drawing. The retort revolves inside the shell, which is of refractory brick insulation and steel shell. The burners are fired tangential to the inside lining, and the heat is controlled by means of automatic temperature regulator. The shells are fed into the retort through the hopper shown on the print of the furnace.

CONTINUOUS ANNEALING FURNACE FOR LOCAL ANNEALING OF THE END OF BRASS TUBES
The tubes are fed on to rails carried above the two pipe burners which heat only the ends of the tubes. The movement of the tubes forward is controlled by the chain conveyor, which rolls the tubes across the heat zone. The tubes are discharged by the rails at the far end into a hopper or quench tank.

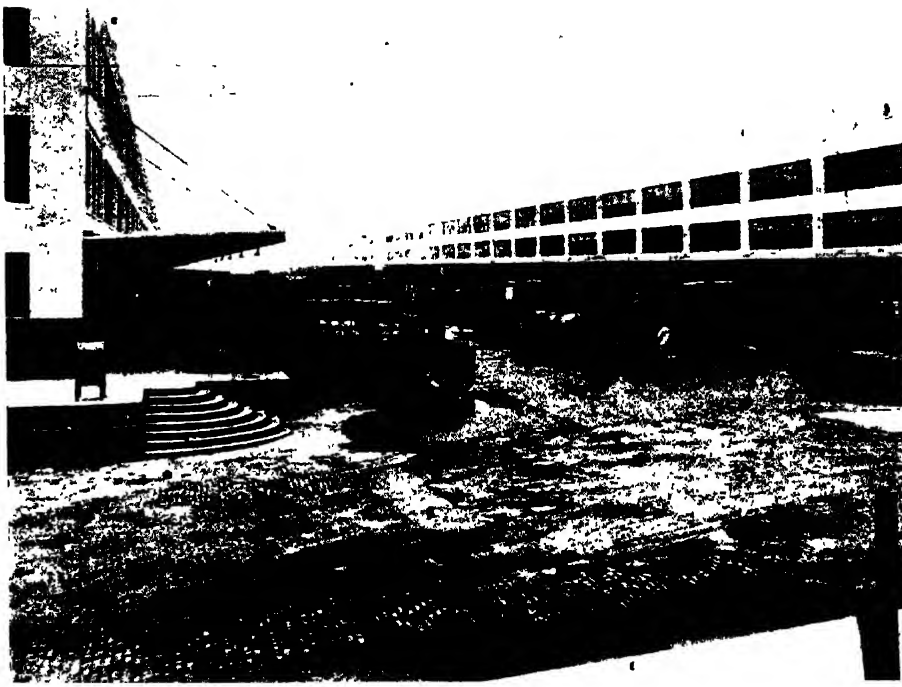
FOOD PRODUCTS



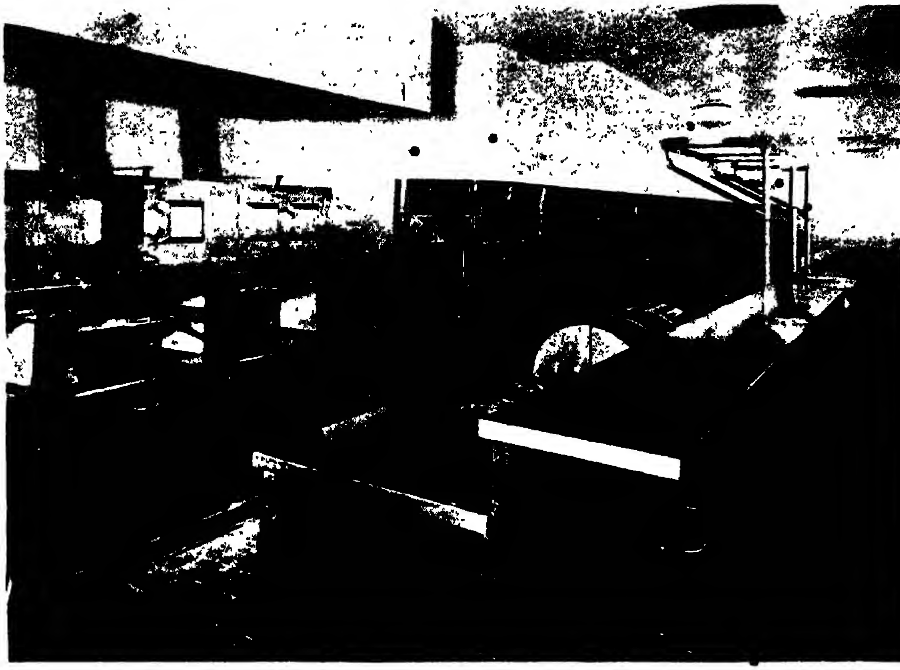
This curve is based on the actual records of one of the largest gas companies in the United States. The whole rectangle represents the product of the maximum day by the 365 days in the year. The shaded portion below the curve represents the sales for each month in terms of the percentage of the maximum dav multiplied by the number of days in the month.

The whole rectangle may also be taken to represent the capital required for the necessary production equipment to supply the maximum day of 100. The shaded portion may be taken to represent the annual daily factor or the amount of capital usefully employed. The unshaded portion represents the idle investment in production equipment.

The annual daily load factor of 84 per cent. realised, amply demonstrates the desirable character to the gas company of the hotel and restaurant business.



A glimpse of one of the markets in Chicago where retailers buy their perishable groceries, etc. There is over one mile of store fronts in this picture. There are one hundred and sixty-one gas services. Everything required with heat is done with gas. This includes coffee roasting, cocoa bean roasting, banana ripening, cheese coating, poultry dressing, nut cracking and scores of other industrial processes.



One of the kitchens in the Hotel Stevens, Chicago, Illinois—the largest hotel in the world. In line with modern practice, this is an "all-gas" hotel. The gas-fired equipment used includes thirty-six sections of hotel ranges, twelve 30-in. broilers, seven 30-in. roast ovens, five 10 12 bake ovens, and one special bake oven, besides a large number of hot plates, chicken singers and waffle irons, etc Practically all of the kitchen equipment is constructed of monel metal of extra heavy gauges.

For the hotel and restaurant gas is an ideal fuel from the standpoint of convenience, cleanliness and economy, which explains why the major portion of this business is handled by the gas company.

The following table gives comparative costs of gas and coal fuel and electric energy when used for commercial cooking. These figures are based on coal ranges developing an efficiency of 10 per cent., gas 40 per cent., and electricity 80 per cent.

Cost of Equivalent Amounts of Fuel

Coal	... $14 per ton	20 lb.	.. 14 c.
Gas	... $ 1 per M.	100 cu. ft.	10 c.
Electricity	4 c. per kWh.	8·3 kWh.	... 33·2 c.

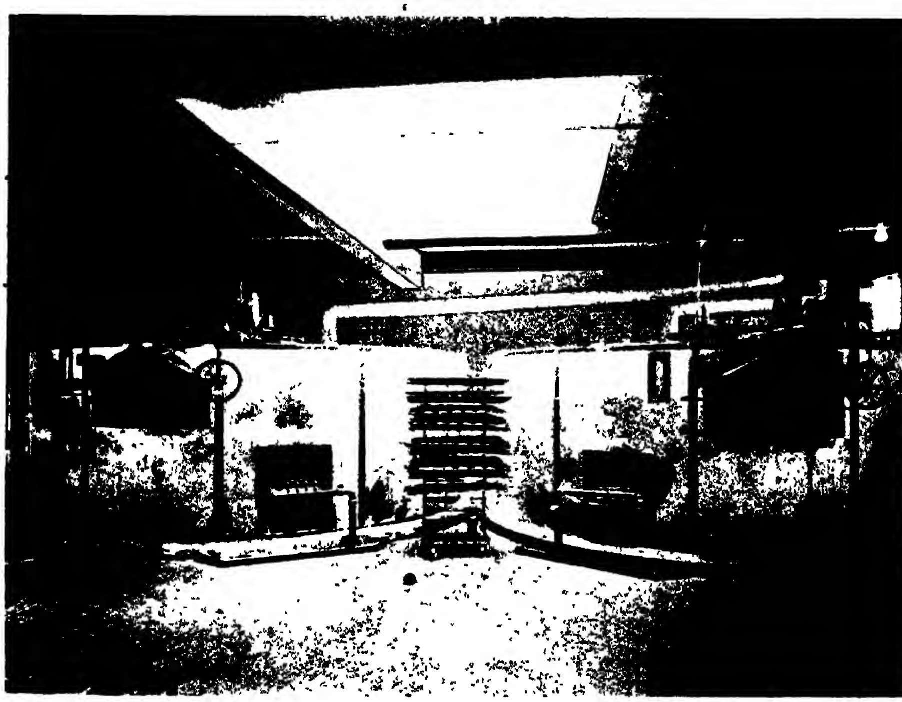
A survey made of seventy-eight kitchen installations in various hotels, restaurants, cafeterias, lunch rooms, etc., serving a total of 58,622 meals per day, showed that 30,148 of these meals were served with 5·1 cu. ft. of gas or less, 21,034 used from 5·1 to 10·1 cu. ft., and 7,440 used over 10·1 cu. ft. Naturally, as the price per meal rises and the number of meals served falls, the gas consumption per meal increases. However, it can be seen that the use of gas as a fuel in this work costs, on an average, less than ½ cent. per meal.

View of a modern type of gas-fired travelling bread-baking oven. These ovens range from 50-120 ft. long and are from 6-10 ft. wide. Capacities will vary from 1,500 to 6,000 1 lb. loaves of bread per hour. Gas is supplied to these ovens at some 80 in. water pressure. Burners are located the entire length of the oven, each having a separate cock so that temperatures in any part of the oven may be accurately controlled. The baking period will vary from 25 to 75 minutes, depending on the goods being baked; and temperatures are usually maintained at 400°F. in the loading end, 450°F. in the centre, and about 420°F. at the discharge end. A gas consumption of less than ¾ cu. ft. per lb. of bread baked may be realised in this type of oven.

For applications of this nature, gas has a large number of advantages, in addition to that of low fuel cost. These include a better product, less spoliage, greater output per unit of floor space, better control, less labour and absolute cleanliness

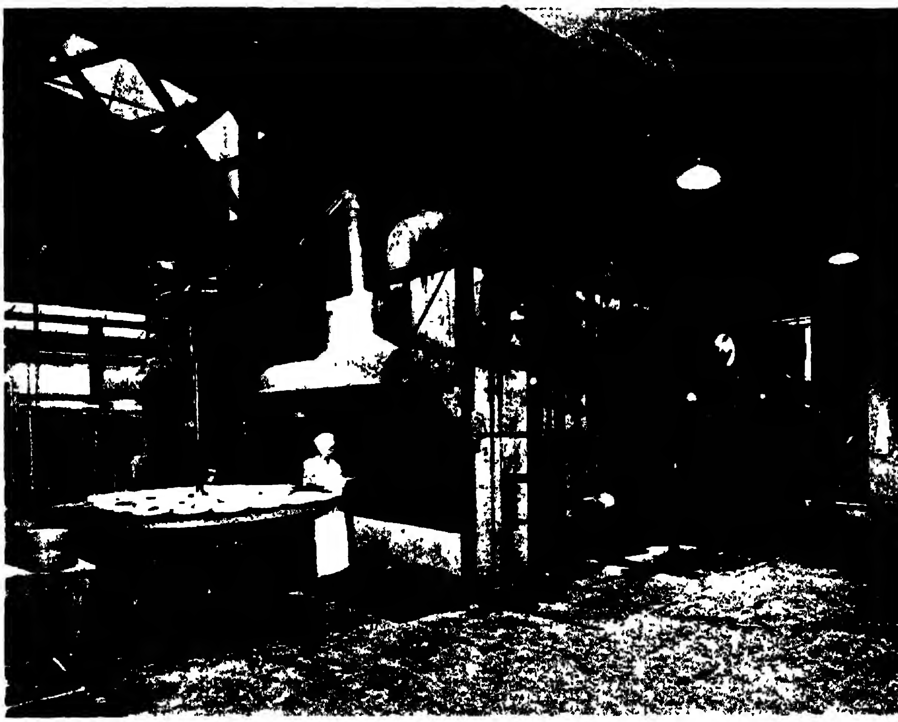
These two conveyor-type gas-fired ovens for baking matzoths in the plant of Harowitz Bros. & Margareten, New York City, are each 100 ft. long. Each oven is constructed with three heat zones thermostatically controlled, the first section being heated to 500°F., the middle to 700°F., and the last section to 600°F.

Each oven has a baking capacity of 1,250 lb. of flour or 1,000 lb. of matzoths per hour. The maximum hourly gas consumption per oven equals 1,800 cu. ft.

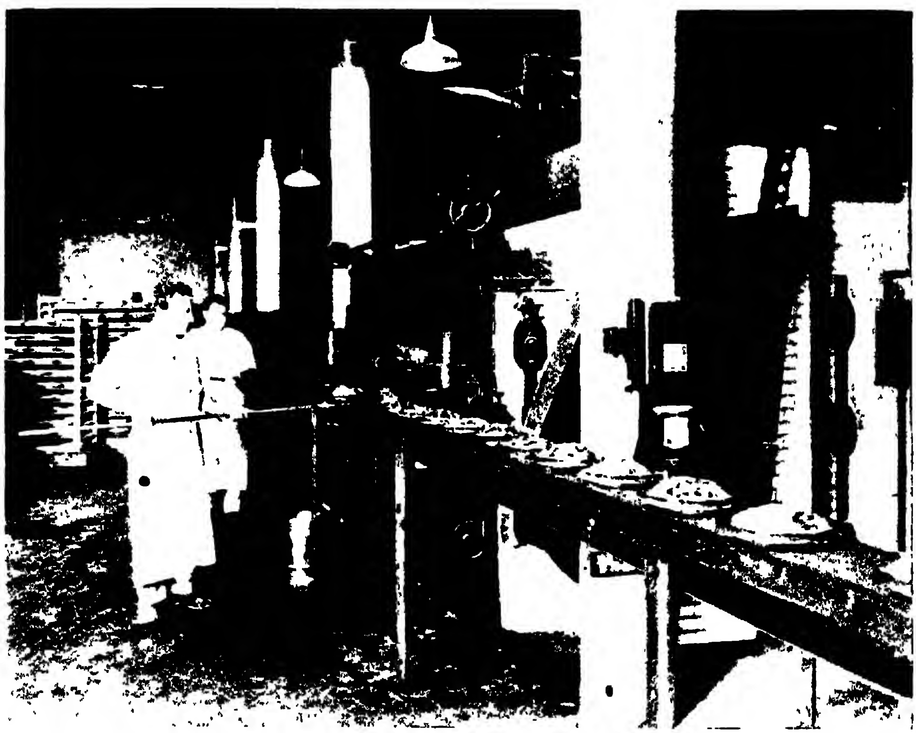


Two 14 ft. insulated portable type of fish rotary plate ovens, which were converted from coke to gas fuel. In this type of oven the hearth consists of an annular ring or plate of soapstone, which revolves in a horizontal plane, bringing every portion of the hearth through the same zones of heat, thus ensuring very even baking conditions. The converted gas equipment consists of a set of pipe burners with projecting ports—each burner having its own control.

Although best results are obtained when using new gas-designed equipment, yet conversions such as this are necessary and very successful in many circumstances.



One of the two 30-ft. travelling hearth pie-baking ovens in the plant of the Consumers' Pie and Baking Corporation, of Brooklyn, New York. Approximately 30 minutes' baking time is required and each oven has a capacity of 1,400 pies per hour. The system of gas firing used is blast burners, in which air is raised to 1½ lb. and blown through injectors by means of which it carries the proper amount of gas with it into the burners. Owing to the difference in the size and weight of various kinds of pies, it is not possible to give the exact fuel ratio per pie, but experience shows the ratio per lb. of pie to be two-thirds of a cubic foot of 565 B.Th.U. gas.

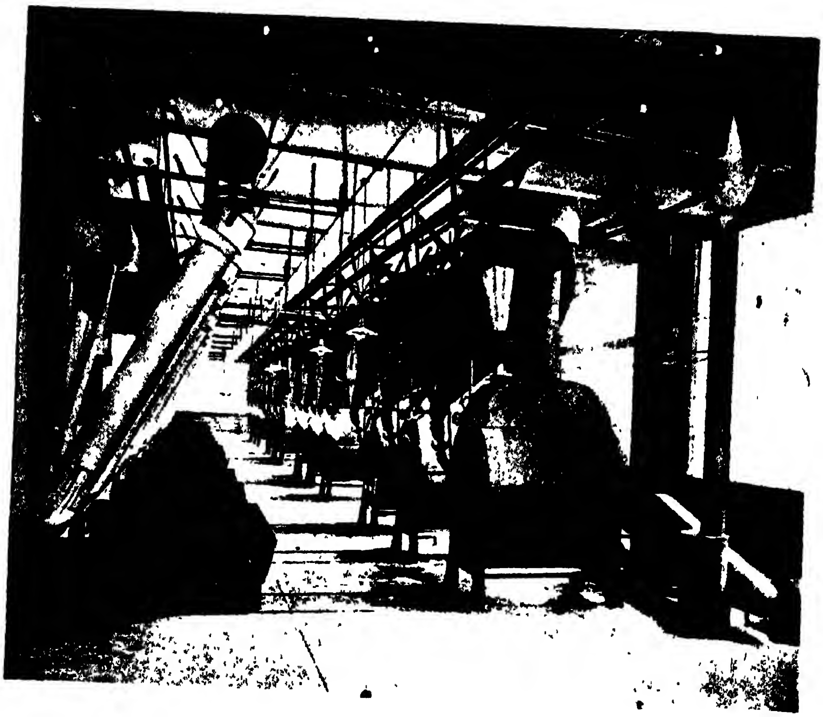


Gas-fired travelling pie-baking oven in the plant of the Patterson Pure Food Pie Company, Chicago. The oven is 95 feet in length and has a capacity of 2,000 pies per hour

This large capacity doughnut machine is installed in the plant of the Purity Baking Company, at St. Paul, Minnesota. Heat is furnished by a 30-bar type atmospheric burner, and the products of combustion are carried through the grease reservoir in the canopy.

In operation, the cutting and forming drum drops forty doughnuts every 13 seconds into the grease trough. They are then carried by conveyors through the heated grease for a distance of 9 ft., where they are given a half turn by a paddle mechanism and conveyed a distance of 7 ft. to a drain and on into an endless belt to the packing room.

On a 24-hour run 19,000 doughnuts were turned out with a consumption of 21,600 cu. ft. of gas. Two men were required on each eight-hour shift, as compared to nine men per shift with the old hand method.



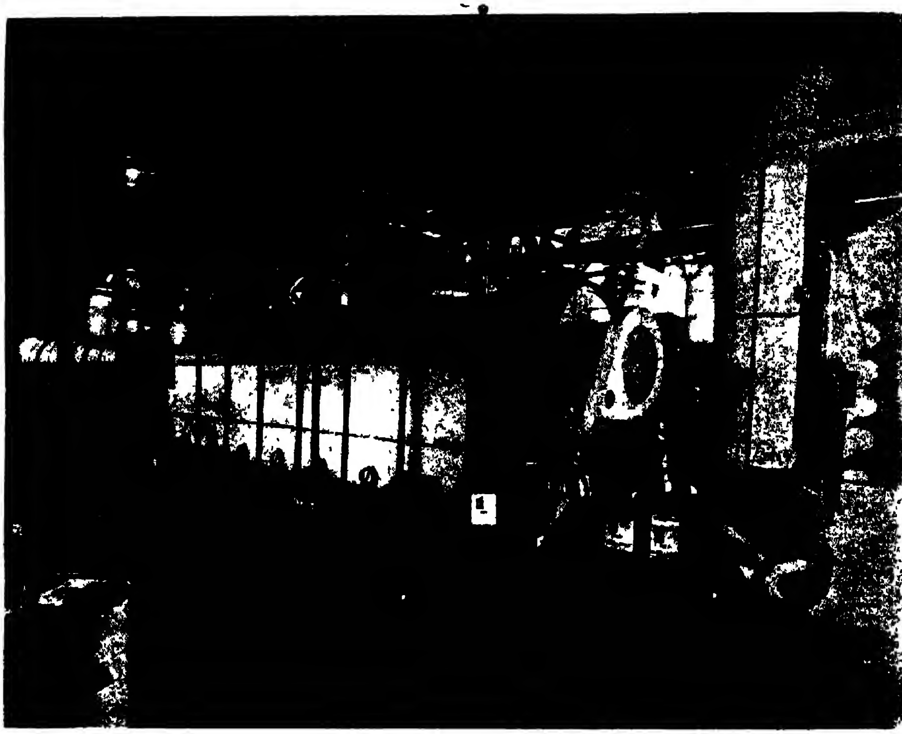
Part of the twelve coffee roasters in the plant of the Jewel Tea Company, at Hoboken, New Jersey. Each roaster turns out 500 lb. of coffee in 21 minutes.

Previous to the use of gas for coffee roasting in this plant, forty-eight coal-fired roasters, each with a capacity of 250 lb. each was required. While it took two men to roast 3,000 lb. of coffee per hour with the coal-fired equipment, one man now roasts 4,500 lb. in the same time. Also the bothersome, smoky coal fires are eliminated.

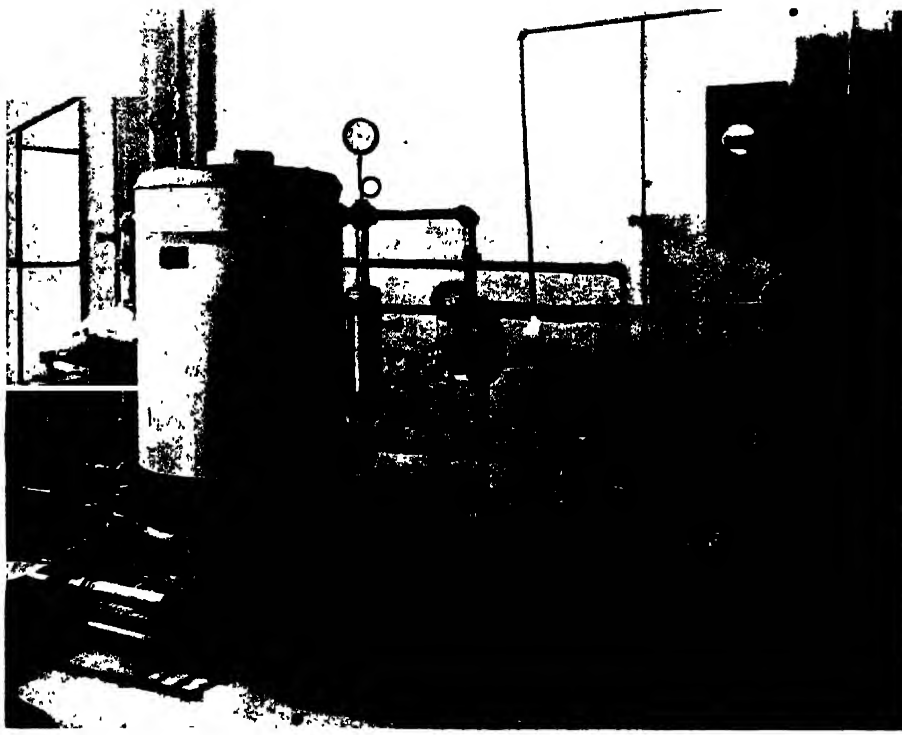
Of the approximately 1,200 coffee roasters in the United States, only about 12 per cent. are still using coal, all the rest having adopted gas. A modern internally-fired coffee roaster requires approximately 90 cu. ft. of a 530 B.Th.U. gas per bag of coffee—or less than ¾ cu. ft. per lb. The usual length of roast is between 18-21 minutes, varying with the grade of coffee. One marked advantage of gas over coal for this work is in the greatly increased capacity realised per roaster—often representing an increase in production of 400 per cent.

The advantages of gas for coffee roasting apply to very much the same extent to cocoa; although the procedure is somewhat different, because the roasting of cocoa removes the hulk as well as drying the bean, darkening the colour and improving the aroma. Operating with a full charge of 550 lb. of cocoa per roast, approximately 300 B.Th.U. are required per lb. of cocoa on converted installations, and 250 B.Th.U. per lb. of cocoa in the case of installations designed for gas. Of course, as the weight of the charge decreases, the fuel requirement will increase slightly.

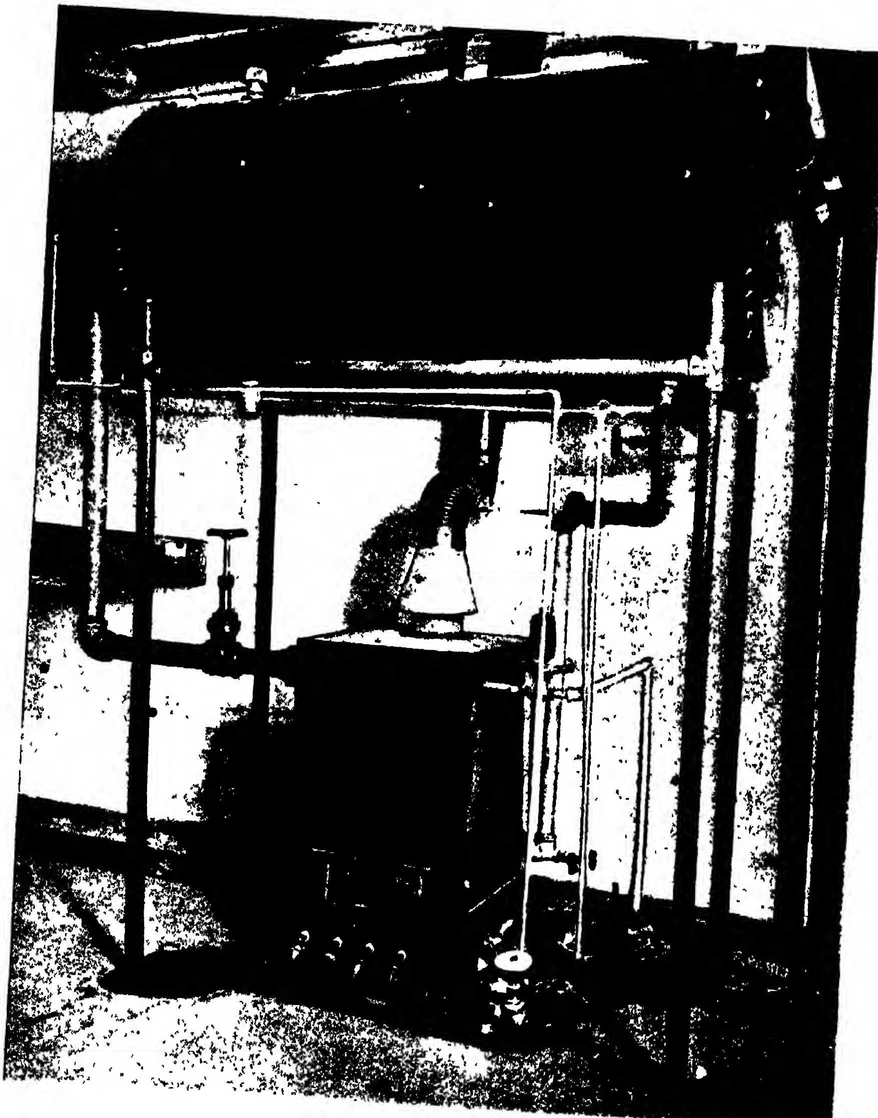
Part of a battery of twenty-eight peanut roasters in the plant of the Curtiss Candy Company, Chicago, Illinois, manufacturers of the "Baby Ruth" candy bar. Each of these roasters, all of which are operated by gas, roasts 400 lb of shelled peanuts every 30 minutes, or a total of 110,000 lb. for the twenty-eight machines every eight hour day. Over one half of the world's production of peanuts is roasted in this plant with manufactured gas.



Part of a battery of cereal roasters in the plant of the Washburn Crosby Company, Chicago. Corn is processed in a syrup and then flaked, after which it is roasted in these continuous gas-fired machines. The gas consumption in this plant is approximately 800,000 cu. ft. per month.



This is a 10 H.P. steam boiler, automatic in every respect. Such boilers are ideal in supplying steam for such processes as soft candy cooking, sterilising and steaming of bread ovens They may be placed on any floor, no coal bins are required, and feed-water supply, pressure and temperature, are all automatically maintained.



An automatic water heater with a 120 gallon tank, installed in a Decatur, Illinois, cafeteria to supply hot water needs. This heater is capable of heating 72 gallons of water per hour with a 100°F temperature rise, and supplies sufficient hot water for dish washing, shower baths, steam tables, three coffee urns and eight sink outlets.

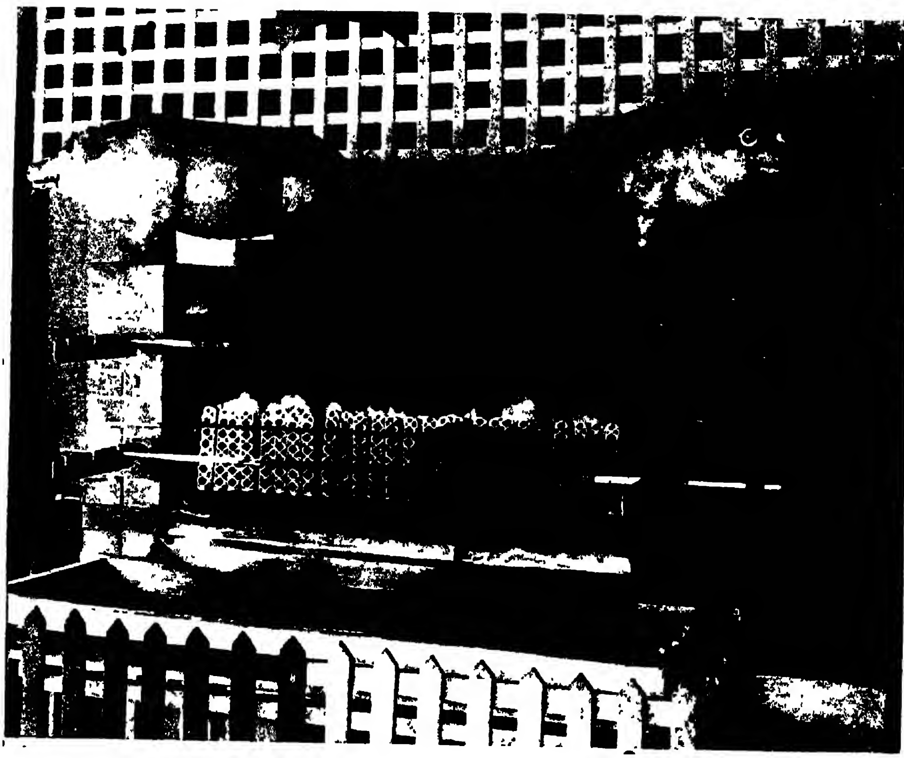
Other gas equipment in this cafeteria, which has a seating capacity of 350, includes two closed-top and one open-top ranges, a two-deck and a four-deck portable oven, and a proofing box, in which is located by a small gas plate. The total gas consumption in this cafeteria averages 10·5 cu. ft. per meal served.

In meat smoking the control of shrinkage is a much greater factor than fuel cost considerations. Only a small saving in shrinkage pays the fuel bill of a quality fuel. Furthermore, exact control of humidity, circulation, temperature and time, is made possible, with duplication of results from day to day and less supervision.

Modern practice is to use gas to produce the necessary heat, and hard wood sawdust to produce the vapours which are desired for smoking. The large smokehouses are equipped with blast burners, both to ensure good combustion and to produce a bed of concentrated heat.

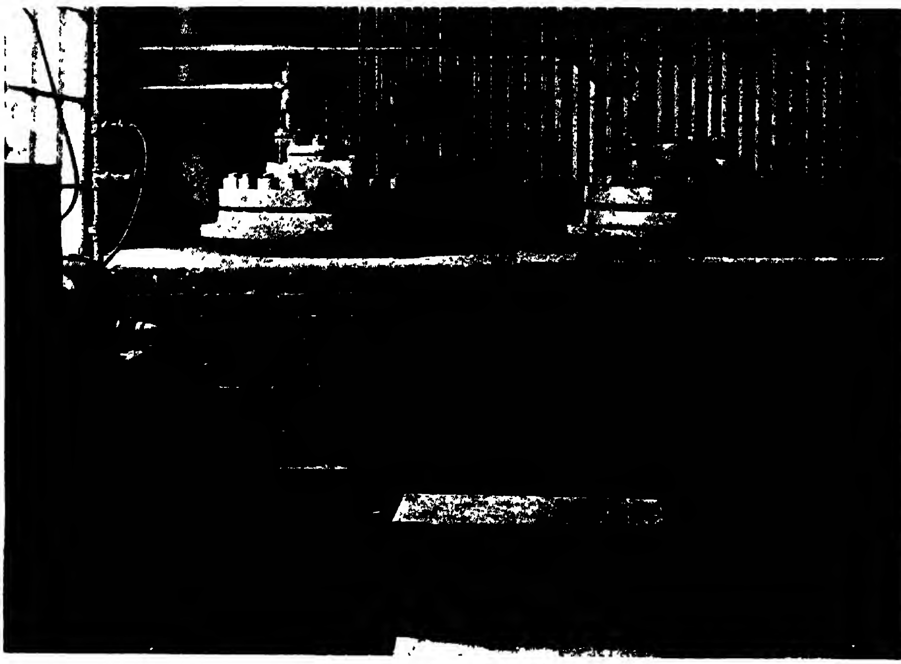
A comparative cost study made on a large smokehouse using wood and sawdust, and a similar house using gas and sawdust, showed on a 13,000 lb. charge of bacon, ham, butts, etc., a smoking cost with gas of $·074 per 100 lb., as compared with a cost for wood of $·305. This saving is accounted for to a large extent by a saving in shrinkage in the case of gas of 1·28 per cent. The saving in shrinkage when using gas as a fuel for smokehouses is of prime importance, as the amount of moisture removed from the meat can be regulated much more closely with gas than with any other fuel.

Gas consumption in smoking operations varies with the time of smoking, size of the smokehouse, etc. From ½ to ¾ cu. ft. of gas per lb. of meat is the average required; while on the basis of smokehouse space, 2 cu. ft. of gas per cu ft. of space is considered average in ham smoking. The usual time allowed for smoking hams and bacon is 16 hours for a light colour, 24-28 hours for a normal colour and as high as 36 hours for the heavier smoked hams.

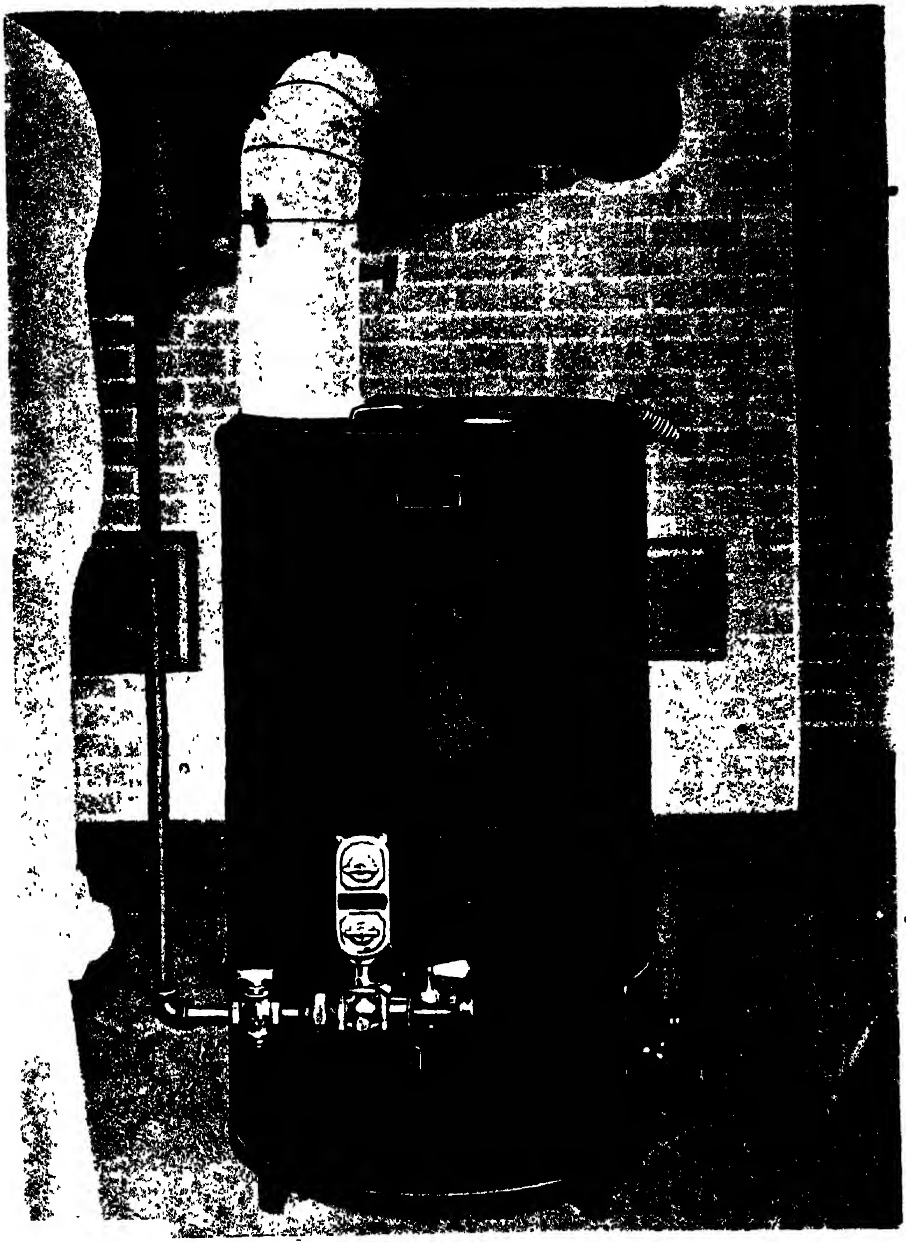


This up-to-date barbecue illustrates one of the less appreciated sides of gas utilisation, namely, its advertising value. Gas lends itself to attractive and novel displays which arrest the attention of passers-by.

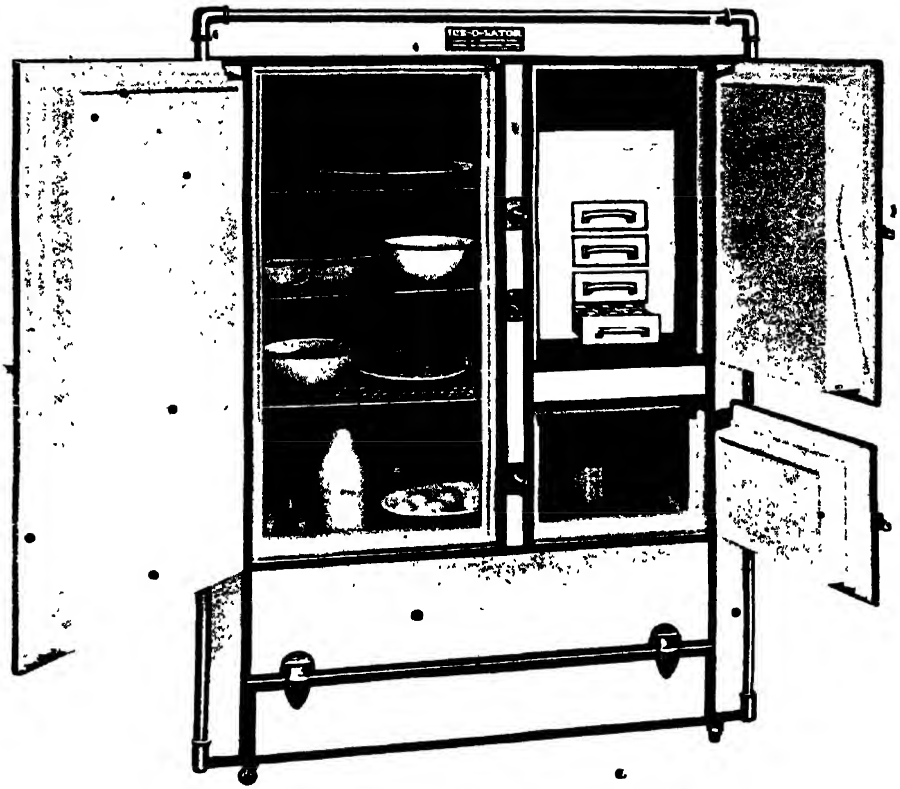
Showing a battery of gas-fired kettles used by the United Happiness Candy Stores in making the "Happiness in Every Box" candies. The fundamental need for cleanliness in candy manufacture is easily realised when gas fuel is used. The uniformity of product obtained and the necessary flexibility of gas in candy boiling, are important reasons for its selection. A test carried out with 56 lb. of sugar mixed with 5 quarts of water, showed that the temperature could be raised to 310°F. in 27 minutes with a gas consumption of 112 cu. ft. of 500 B.Th.U. gas. In another test with a standard type of gas-fired confectionery furnace, 181 batches were cooked in a period of eight days—average time of 17·2 minutes per batch. 28,150 cu. ft. of 550 B.Th.U. gas were used. With gas at $1·00 per M. cu. ft., the total cost including labour, equalled $0·393 per batch. In the case of coke fuel at $6·00 per ton, the total costs were $·401 per batch—with all the disadvantages of a solid fuel.



This picture represents two high-pressure autoclaves heated by means of gas burners. These autoclaves operate at pressures up to perhaps 1,000 lb. or so per square inch, at temperatures ranging from 300°F. to 600°F. or over, and are used in the manufacture of food colours



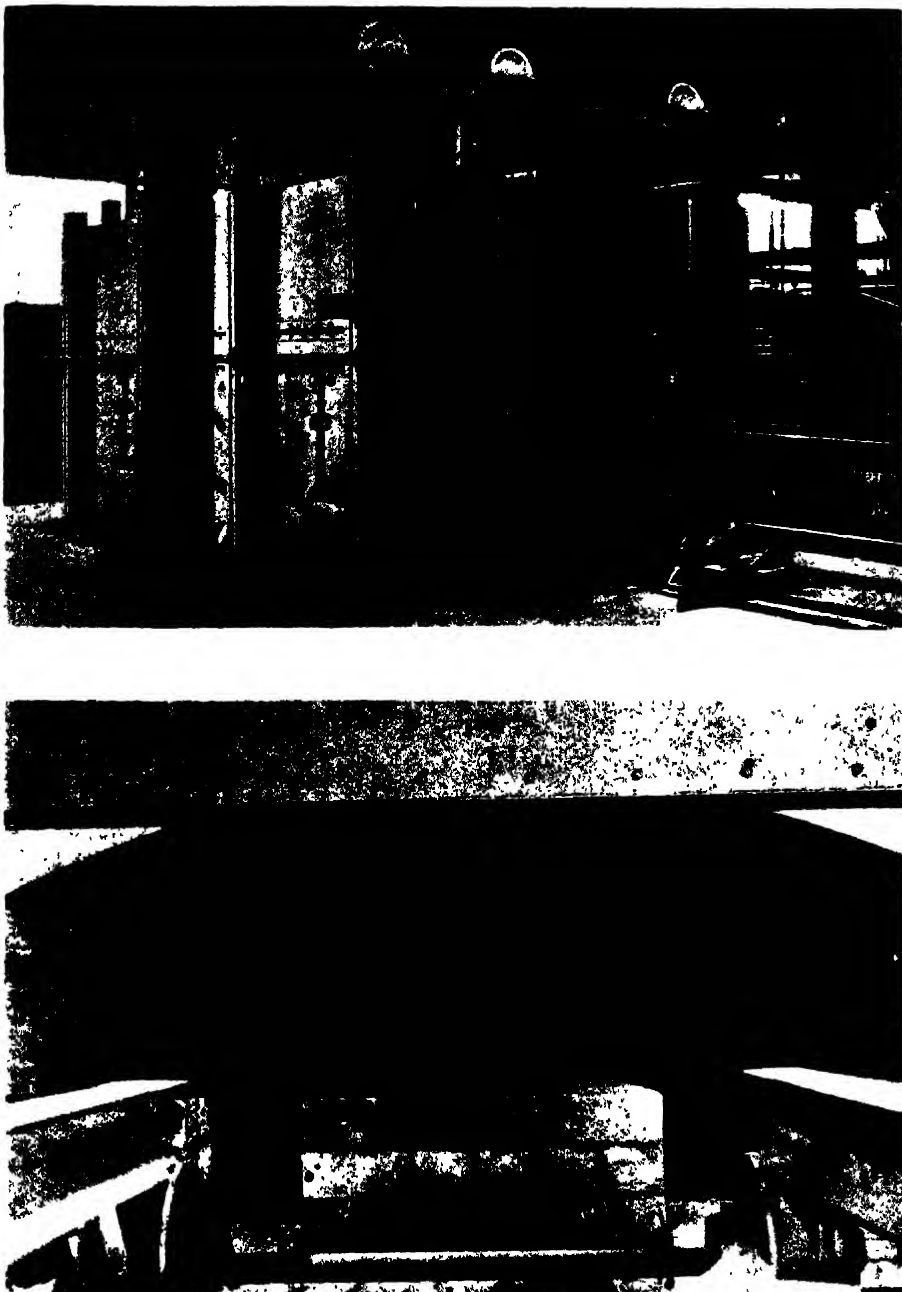
The gas-fired incinerator is an efficient and space-saving medium for the disposal of waste and garbage in both home and restaurant. In the latter it is of especial value, particularly in basement restaurants where air circulation is apt to be less than in dining rooms with windows. Under these circumstances the incinerator eliminates all odours attributable to food spoilage.



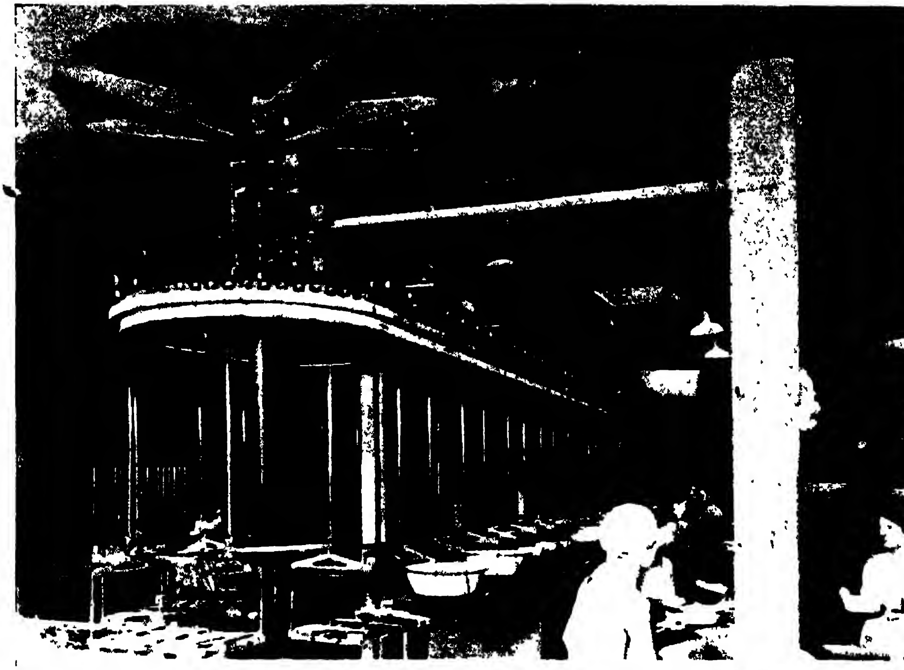
Refrigeration by gas represents, in the opinion of many experts, the best method of food preservation for home and restaurant. There are no moving parts either to wear out or cause noise, and as a result no attention is required. Furthermore, with the average gas rate, it is cheapest of all to operate.

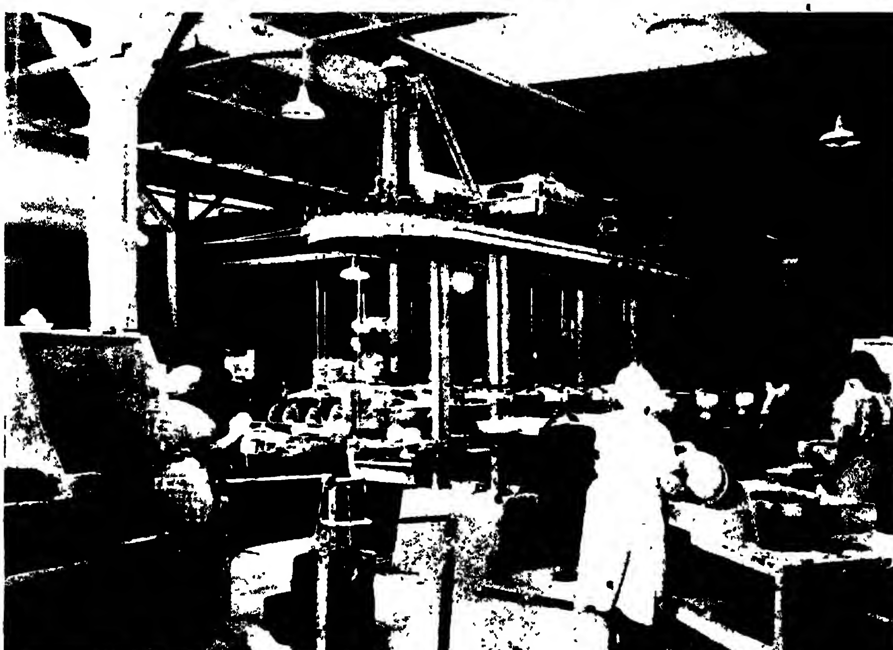
The field for the gas unit for commercial refrigeration has scarcely been touched and offers a considerable potential field in hotels, restaurants, clubs, schools, diaries, meat markets, etc.

CERAMICS



Periodic type of enamel furnace, gas-fired, in use at one of the plants of the American Stove Company

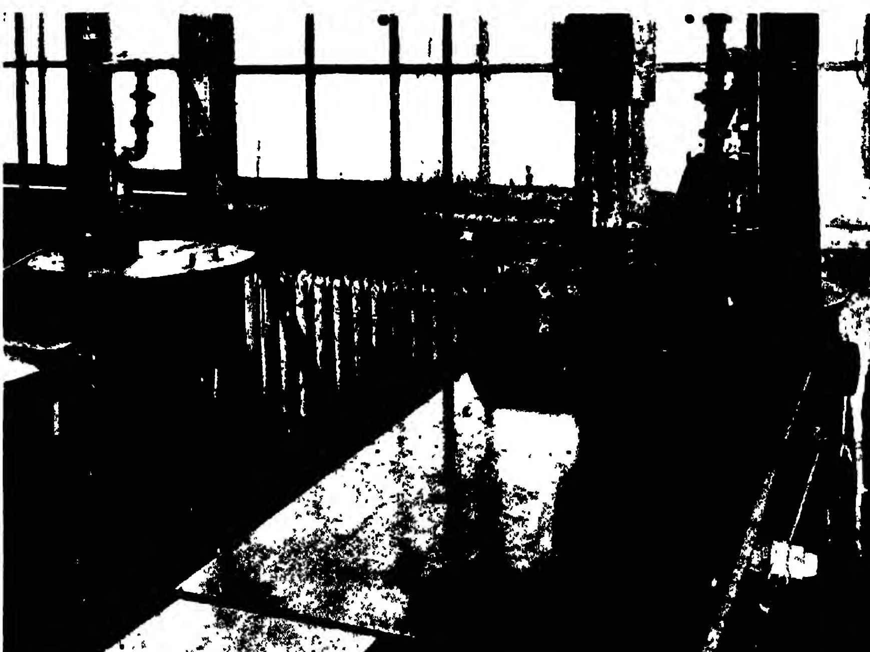




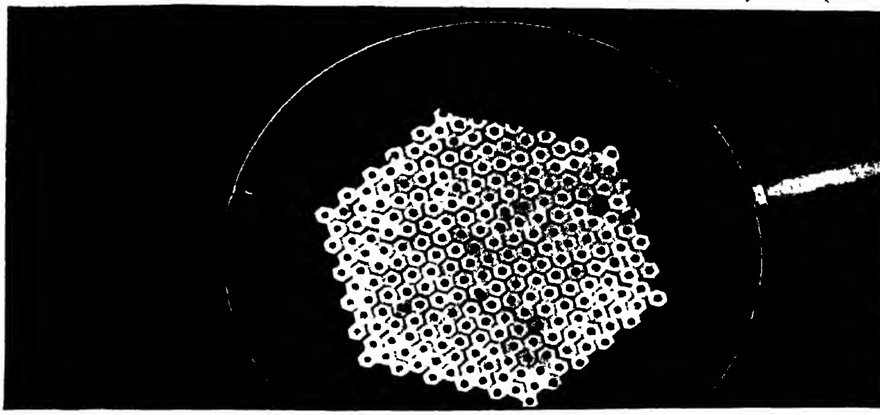
Continuous and automatic gas-fired furnace for burning enamel on metal ware. Conveyor extends from both ends of furnace and ware is dipped and hung on it directly and it is then moved through the heating chambers. Each side of the furnace is maintained at a different heat to accommodate the ground and white coats respectively.

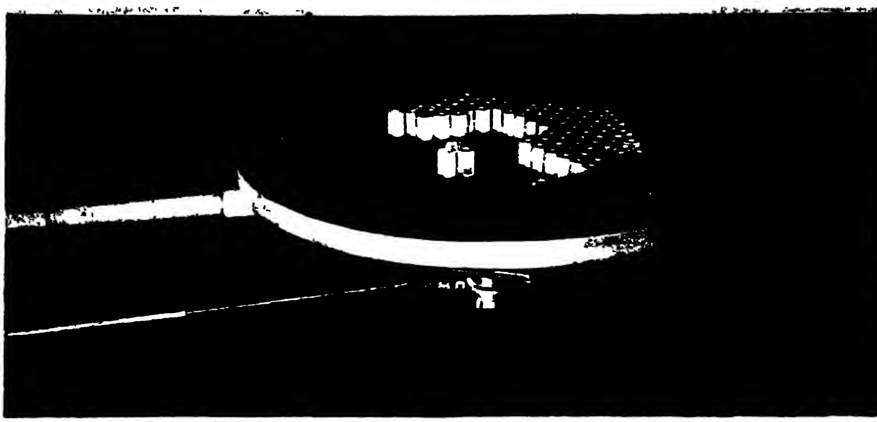
Continuous glass kiln at the plant of the Kimball Glass Company.

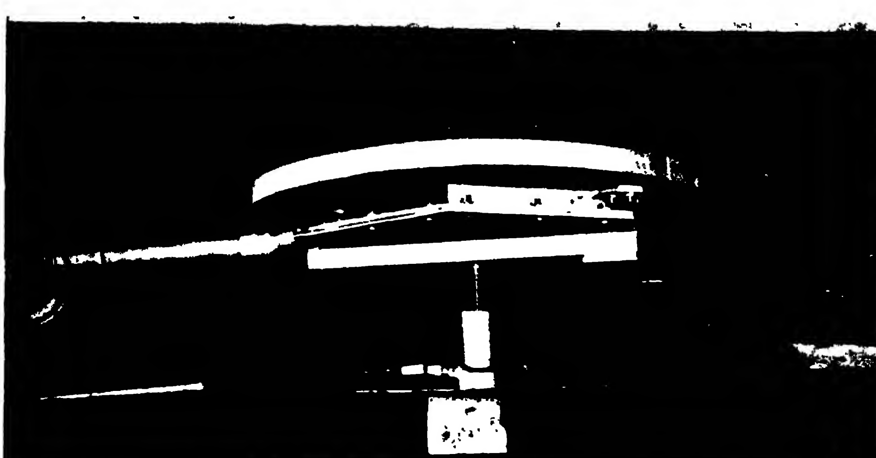
Inlet end and pre-heat zone of gas-fired tunnel kiln used for burning electrical porcelain. Isolantite Company of America.



Gas-fired kettles, thermostatically controlled, for melting wax. Wireless Specialties Apparatus Company.

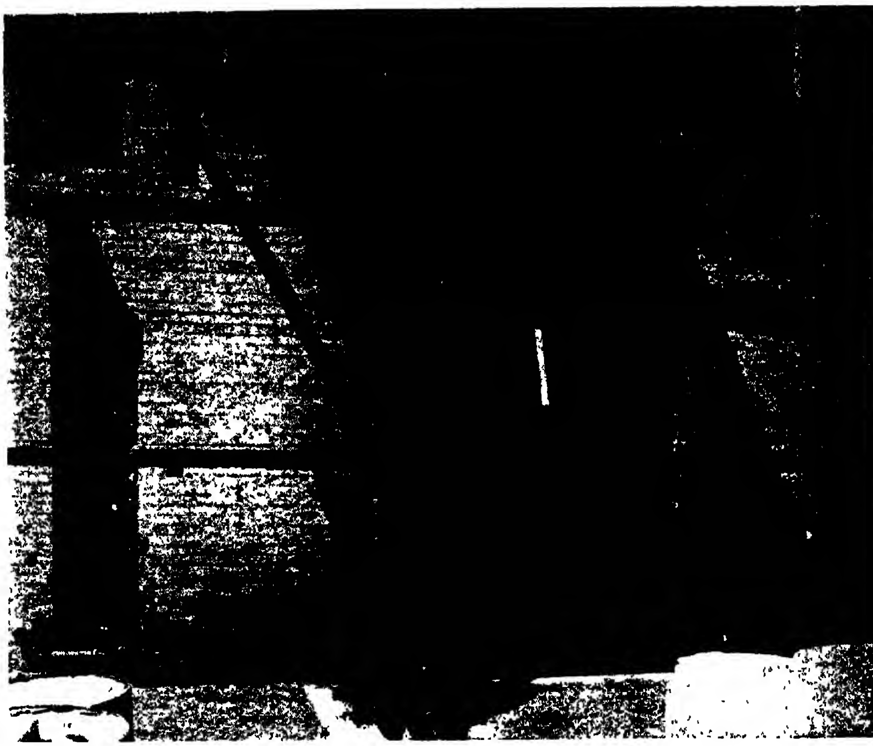






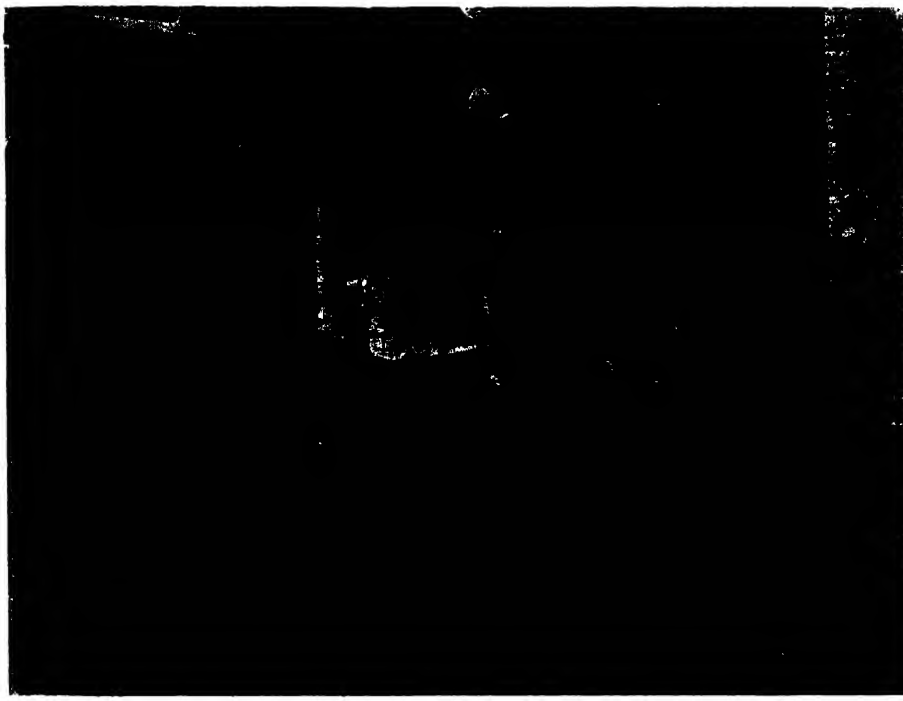
A new burner has recently been developed and tests at a big varnish plant showed the following results:—

1. Has a 12 per cent. higher thermal efficiency than any other burner, oil or gas, on the market.
2. Cooks varnish 30 per cent. faster than any oil burner on the market.
3. Cooks varnish approximately 50 per cent. faster than any other gas burner on the market.
4. Cooks varnish approximately 75 per cent. faster than the average coke fire.

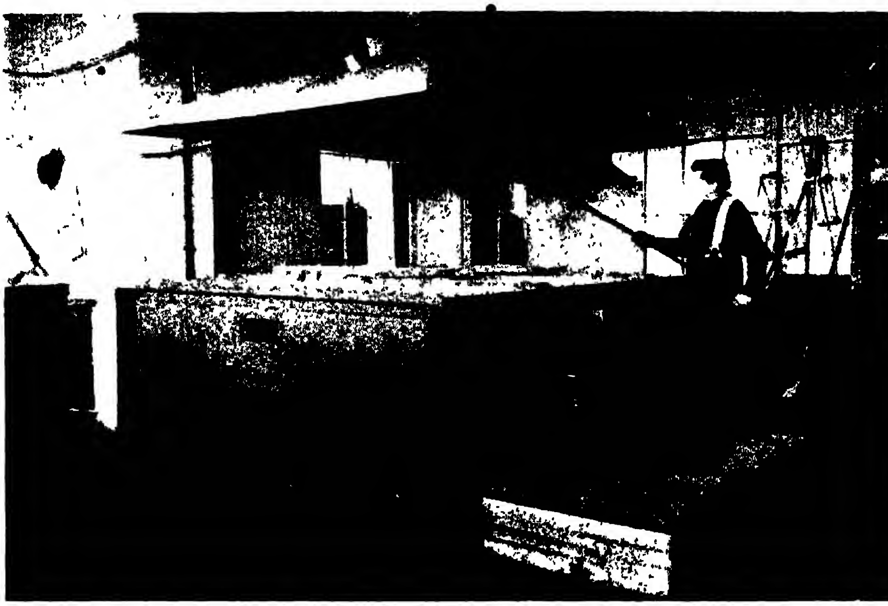


This gas-fired tank used for heating tar is part of a roofing plant and is 22 ft. long and 11 ft. in diameter. It is kept hot from heat that is reflected from a carborundum bed in which gas is burned directly. High-pressure burners are used which make it possible to utilise the one-valve control and to maintain a very uniform temperature at all times.

By burning the gas at high-pressure and radiating the heat from the carborundum bed, direct flames are prevented from coming in contact with the bottom of the still. Up to the time of this new method, frequent replacement of the still proper was necessary, due to warpage and opening up at the seams.



Litharge and red oxide of lead is produced in gas-fired furnaces at the Chicago plant of the National Lead Co. The furnaces are of the reverberatory type and in each is placed a pan holding 3,000 lb. of molten lead. There are eighteen burners arranged in a row on one side and firing across the top of the pan. Excess air, pre-heated, is forced in to promote oxidation. The product is litharged and another burning produces red oxide of lead. These furnaces are 14 ft. wide, 12 ft. deep, and 8 ft. high.



Calorising consists of dipping the work into molten tin and then into molten aluminium. At the Edison Electric Appliance Company, an installation for this process consists of two cast-iron pots held in a brick structure containing a combustion chamber. This structure is 12 ft. long, 9 ft. wide, and 11 ft. deep. The pots are 33 in. long and 30 in. wide, while they taper in width from 12 in. at the top to 4 in. at the bottom. Heat is applied by four gas burners for each pot, twelve firing at each end and the flames impinging.

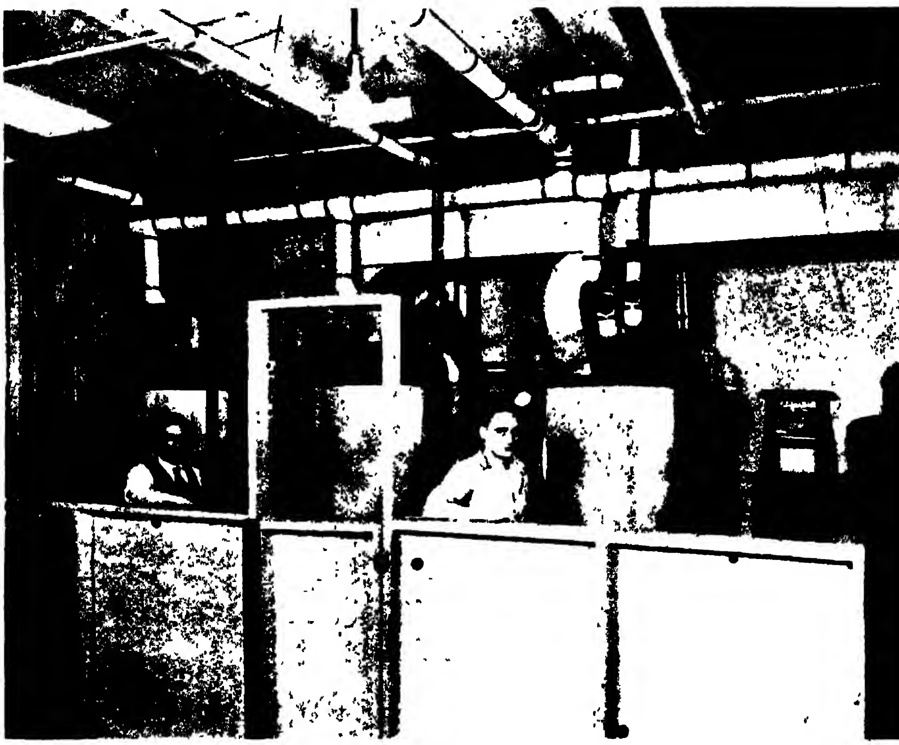
Inspirators are supplied to control the atmosphere for the prolongation of the life of the pots, and to supply air for a correct gas-air ratio to ensure perfect combustion and minimise fuel consumption. The elements to be calorised are first dipped into the tin, then into the aluminium. The first is carried at 600°F. and the latter at 1600°F.

Battery of Thrift ovens used for baking and conditioning radio condensers. Wireless Specialties Apparatus Company.

A popular type of japanning oven is continuous and automatic in its operation. The work is hung on the conveyor rods, automatically carried down through a vat of japan and then up through the heating chamber, the cooling chamber, and out at the discharge end. The oven shown has a capacity for 6 tons of work hourly. The temperature may be maintained up to 450°F., with a gas consumption of approximately two-thirds of a cubic foot per lb of work japanned. A great saving in labour, spoilage, time, space, fue., etc. was effected by this oven.

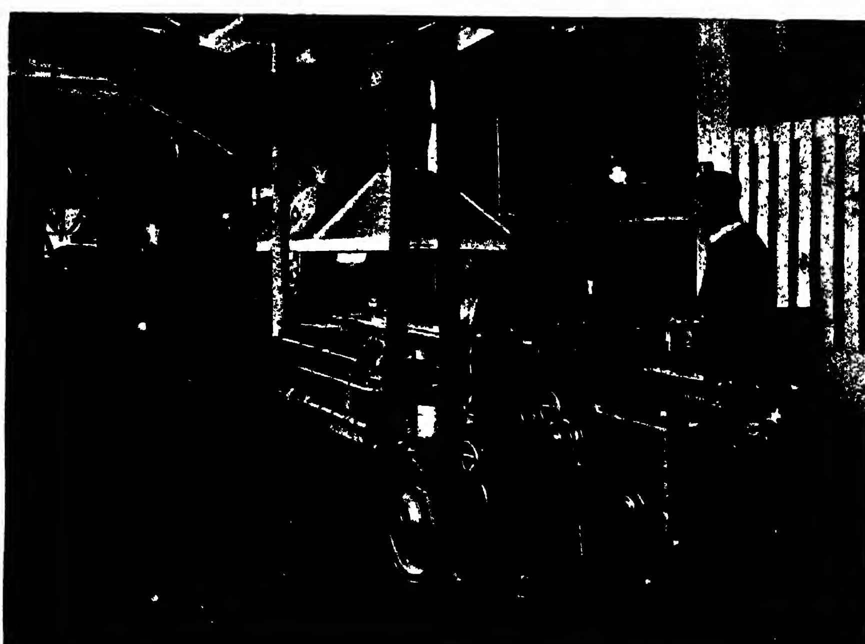
LITHOGRAPHING OVENS (Photo A)
The view shows the feed end of three lithographing presses. Each of these presses is directly connected to a gas-fired travelling oven in which tin sheets are dried. They are lithographed in colours (in some cases as many as 10).
Anchor Cap and Closure 60.

In lithographing block tin for the manufacture of various commodities, it is necessary to dry the paint or ink, and gas is employed for this purpose Conveyor chains run the entire length of the oven. The work is put in at one end, carried through the hot zones which are heated with gas burners, and the dried product is delivered from the opposite end of the oven



VIEW OF THREE 10 H.P. BOILERS.
Three of a group of eight 10 H.P. boilers in this clothing establishment are shown. They operate at 60 lb. steam pressure, are equipped with automatic feed devices, and built in accordance with the standards of the A.S.M.E.

View of Men's Clothing Manufacture
Various pressing machines operated by steam are shown in this view. All the pressing operations, as well as the shrinking of cloth, are done by high-pressure steam from small portable boilers.



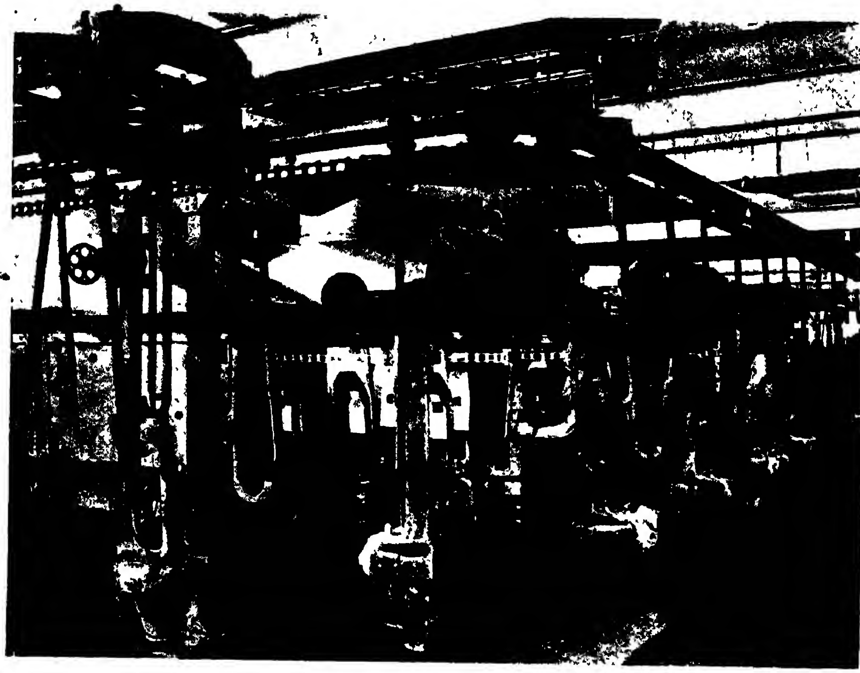
Can Making Machine
This machine, fed by rolls of strip tin plate, automatically forms can bodies with a double lock seam which is soldered as the cans pass over the bath of melted solder. The solder bath is gas heated.

GAS SOLDERING

Soldering connections on small electric cells for the manufacture of radio batteries at the Ever-ready plant of the National Carbon Co. Each of these small cells is complete in itself with positive and negative poles, but must have the connections soldered together in such a way that all the cells form one large cell with the desired capacity. The soldering irons are heated in small gas furnaces.

Brazing torches utilising air and gas are used in soldering battery terminals.

There is a setup at the Fordson plant of the Ford Motor Company for welding defective castings such as tractor cylinder blocks and heads. This consists of a travelling conveyor which runs through a pre-heated furnace, makes a complete turn and travels back through an annealing furnace, parallel to the first. The blocks are pre-heated, welded on a roller table at the end of the conveyor by workmen, and returned through the annealing furnace in a stream.



Crank case department at the Fordson plant of the Ford Motor Company Three gas-fired furnaces, 30 ft. long, with brazing pots and chain conveyors running through them Chain conveyors also serve the department

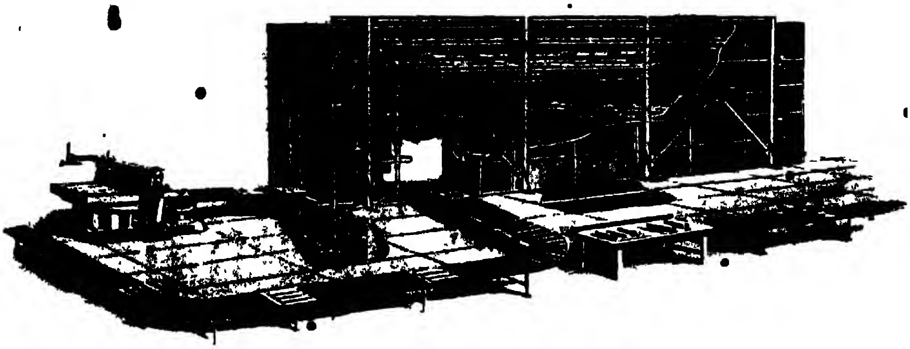
Oxygen and City Gas-Cutting Torch

The cutting torch is mounted on a traveller, which keeps the torch on a straight line.

Portable gas rivet heaters used in erecting the steelwork of buildings Photo shows use on modern 26-storey office building, when 93 tons of rivets were heated and driven while erecting steel work.

Core baking by gas is quite general, and where the volume of foundry production is large enough to warrant it, large ovens which operate continuously and automatically, are used. At the Dodge Bros. Co. plant are five core ovens, each 100 ft long, 10 ft. wide, and 12½ ft. high, fired with gas and equipped with continuous travelling conveyors with cradles.

These ovens are located on the third floor, while the core-making machines are placed on the second. The conveyors leave the ovens through slots in the bottom at either end, pass through the floors and ceiling, and travel along in the core room below for the length of each oven. The operators make up the cores and place them on the cradles, which move up and into the ovens automatically with the conveyors. Pyrometric controls maintain a temperature of 450°F., while the baking periods range from 1½ to 3 hours according to the size of core, character of mixture, etc. The capacity of this core-making and baking department is 250 tons of cores per day, requiring from five to six carloads of sand.



There has recently been installed in the core department of the Bond plant of the American Radiator Company one of the most modern and efficient core-baking units in the country It is a combination of gas-fired oven and travelling conveyor system, which is continuous in operation and automatic as to temperature and baking period.

The core-making section of this department has also been equipped with conveyors, with the moulding machines arranged along both sides so as to synchronise the two operations of making and baking. This also establishes a definite time schedule and allows of very close control.

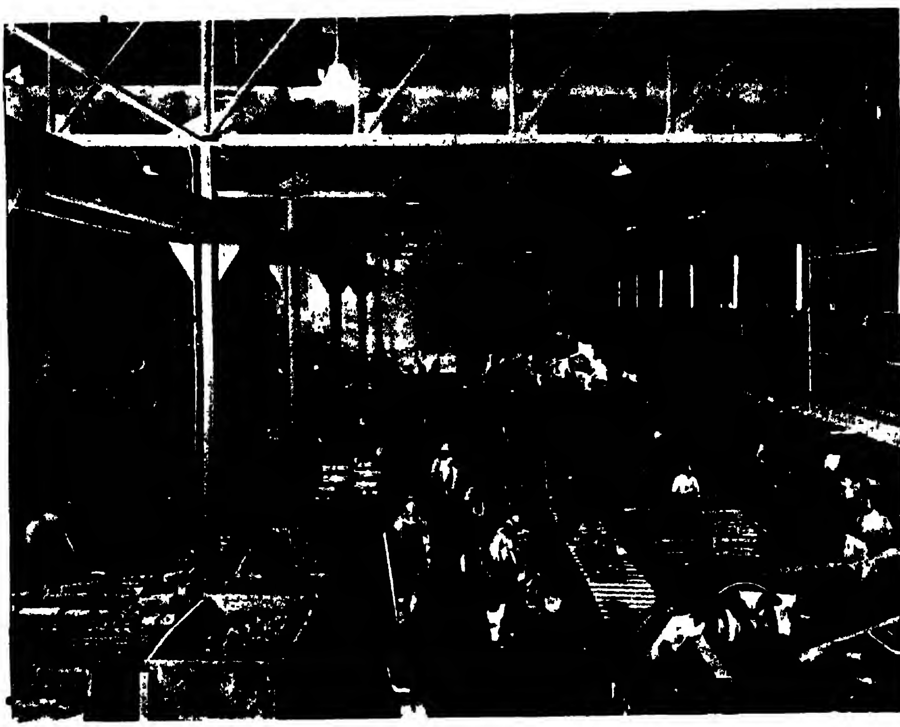
The discharge end of the conveyor is adjacent to the charging end of the oven, from which protrudes a loading platform of rollers The cores, which are quite heavy, are transferred from the conveyor to the dryer plates by means of an overhead monorail with pneumatic hoist. From here they are rolled on to the oven conveyor shelves.

This oven, which is built of steel, has walls filled with 4 in of insulation. It is 74 ft. 6 in. long, 7 ft. 8 in wide, and 19 ft. high. The conveyor consists of two endless chains supporting a series of shelves and driven by a motor through speed reduction gears. The cores make four horizontal passes through the oven, returning at the top and are discharged at the charging end.

There are 279 ft. of link chain weighing 13 lb. per foot and supporting sixty-two carriers or shelves. The shelves weigh approximately 96 lb. each and hand down 12 in. This oven is fired with gas through twenty tunnel-type burners, which fire into ducts 9 in wide and 15 in. high running across and distributed along the length of the oven approximately 3 ft. centre to centre. Two burners fire into each duct, one from each end, leaving ten burners to a side.

The burners are connected to high-pressure inspirator sets in series of three and four burners per set. The re-circulation method of firing is used, whereby the mixture upon entering the duct entrains some of the products of combustion, thereby causing circulation of the gases in the oven and ensuring an absolute even temperature at all times.

The temperature of the oven is maintained through two automatic temperature controls, and the baking period is regulated by the speed of the conveyor. Due to the uniformity of temperature, the quality of cores baked in a gas-fired oven is much higher than those baked in an oven using other fuels. With the use of an automatic continuous oven, a material reduction in time, labour and fuel consumption is realised, and the whole process of making and baking cores is speeded up, effecting economies all along the line.



FOUNDRY
General view of a foundry in which all the cores are dried in continuous core baking ovens

UTILISATION OF ELECTRICITY FOR INDUSTRIAL HEATING

NATIONAL ELECTRIC LIGHT ASSOCIATION AND AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

W. H. SAMMIS

Paper No. K18

CONTENTS

INTRODUCTION

The utilisation of electricity for industrial heating has long ago passed through the experimental stage. To-day, equipment utilising electric heat has been standardised and found to operate with most satisfactory results from the simple glue pot to the furnace melting brass or steel. To-day it is estimated there are more than 2,000,000 kW. being utilised for industrial electrical heating in the United States, and the field for the application of electric heat is practically unlimited. Almost every industrial plant offers possibilities for its application.

Present knowledge does not permit of any accurately defined limits in the field wherein electric heating service may be successfully applied to the needs of the industry. The constant improvement in electric heating equipment and the growth of knowledge regarding its use, combined with the steadily decreasing cost of electrical service, make it impossible to say with assurance that any industrial heating process may be safely regarded as definitely and finally outside of its field.

A survey made by the *Electrical World*, the results of which

were published in the May 8, 1926 issue, indicates that there is an industrial electric heating load, including commercial electric cooking and baking, of 47,000,000 kW. available in the United States. This would indicate that the present field has been developed to the extent of approximately 4 per cent. only.

The present industrial heating load, according to best estimates, is slightly more than 10 per cent. of the total present motor load served by central stations. The available industrial heating load has been estimated at from two-and-a-half to four times the present motor load.

Electricity has not been utilised for industrial heating as a result of its low B.Th.U. cost, for in comparison with some fuels, its B.Th.U. cost is often higher. The accompanying advantages and the overall cost of the product have been the determining factors that have resulted in the wide adoption of electricity for heating in industry. In many processes the saving in rejections alone has more than offset the entire cost of electrical energy. The use of electric heat has made possible the use of various labour-saving equipment. The control of temperature possible with electric heat, and the ease with which proper heat distribution is obtained, enables the product to be duplicated with the minimum of rejections, eliminating sampling and other precautions which might be termed almost laboratory in character. Improved working conditions, considering both heat and cleanliness, have made the adoption of electric heat popular with the men actually engaged in the production of the product, resulting in more harmonious working conditions. In many cases the fire hazard has been reduced, and in some instances this has been recognised by the insurance companies to the extent of reducing the cost of insurance. In addition to the above, each particular application has its distinct advantages.

The following is a reasonably complete list of heat applications in which there is already a record of successful use of electrical apparatus, and for which efficient and dependable equipment is obtainable, but which is far from being completely developed.

1. Metal melting.
   (*a*) Steel and grey iron.
   (*b*) Brass and copper.
   (*c*) Nickel alloys.
   (*d*) White metals.

2. Furnaces operating at temperatures above 1,000° F.
   (A) Heat treating.
      (a) Normalising.
      (b) Ageing.
      (c) Annealing (iron, steel, copper, brass, aluminium, etc.).
      (d) Carburising.
      (e) Hardening.
      (f) Tempering (400° to 1,100° F.).
      (g) Forging.
   (B) Vitreous enamelling.
3. Ovens operating at temperatures up to 1,000° F.
      (a) Japanning.
      (b) Core baking.
      (c) Glass annealing.
      (d) Firing of decorated glassware.
      (e) Bread and cracker baking—toasting cereals.
      (f) Sherardising and galvanising.
      (g) Roasting machines.
      (h) Shoe conditioning.
      (i) Miscellaneous baking and drying operations.
4. Commercial cooking and baking.
5. Small unit applications.
      (a) Cartridge units.
      (b) Immersion heaters.
      (c) Space heaters.
      (d) Clamp-on heaters.
      (e) Standard small units, such as glue pots, hot plates, soldering irons, compound and grease melting, etc.
      (f) Air heaters.
6. Electric welding and rivet heating.
7. Electric boilers.
8. Heat applications in electro-chemical and electro-metallurgical processes.

METAL MELTING

The electric melting furnace first came into use for making high-grade alloy and tool steels. During this development the electric furnace had to compete with the crucible process, which has certain inherent disadvantages in regard to size of crucible, labour required, and variation of analysis of the metal from various crucibles that might be poured into the same mould. As the

electric furnace industry progressed, the furnace became relatively more efficient and economical, so that the crucible process has practically disappeared.

Later, the electric furnace entered the field of ordinary carbon steel castings, where it met the open hearth furnace in the larger plants and the side-blown converter in the smaller plants. Both of these latter processes are oxidising in nature, so that it is difficult to make good solid castings free from slag inclusions, blow-holes, and hard spots. The control of the analysis of the metal is much

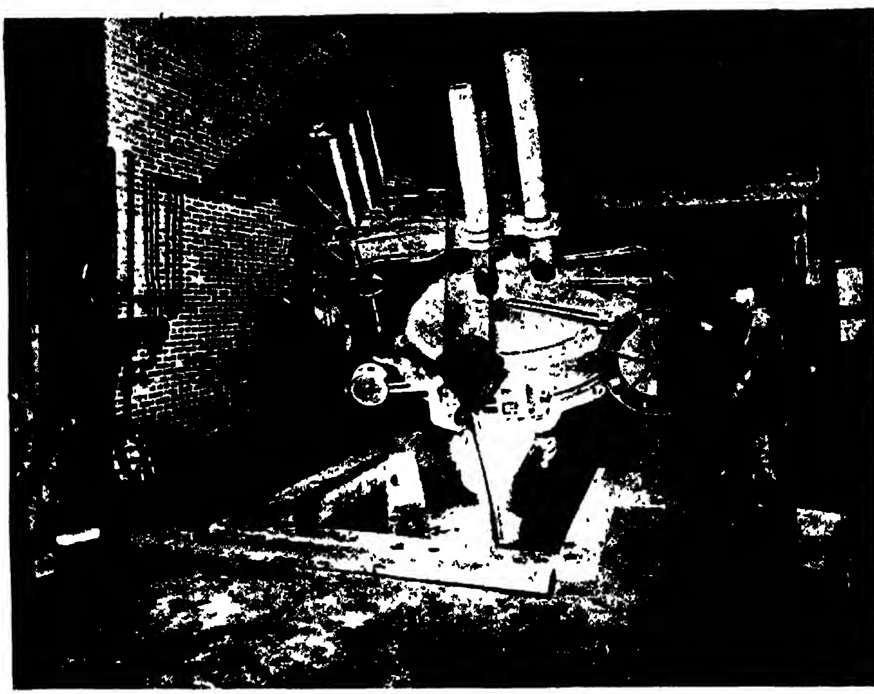


Fig 1. One-and-a-half ton arc furnace pouring steel.

more certain in the open hearth furnace than in the converter, but the open hearth furnace is not particularly adapted to foundry use, as most steel foundries operate on a single turn day. As a result of the fact that with the electric furnace the atmosphere can be made oxidising, reducing or neutral as desired, thus making the control of the analysis more accurate, coupled with other advantages, the electric furnace is rapidly being adopted by the steel casting industry and is generally accepted as the best melting medium in the steel casting work. (See Fig. 1.)

The field of grey, malleable and alloy irons is, however, far larger than the steel field. In recent years, due, no doubt, to the competition of steel and malleable with grey iron, there has been increasing interest in any means whereby a better grade of iron could be had than with the usual cupola method. Further, the large volume of scrap available from the individual industries has given the electric furnace an impetus in this field, as it can be operated on all-scrap charge. The electric furnace, as a result, is rapidly gaining headway in the grey iron field. Furnaces have been built for steel, malleable and grey iron, melting from the small sizes up to sixty tons in capacity.

The use of the electric furnace for melting yellow brass has been adopted almost universally for rolling-mill work, and at the present time a similar revolution is taking place in general foundry practice. Melting in pit furnaces has the disadvantage of high crucible cost and large metal loss by volatilisation, the cost of either over electric furnace operation being in many cases more than the cost of electric heat.

The induction type furnace and the arc furnace are the two types principally used, and range in capacity from 250 lb. to 3,000 lb. per heat.

The use of the electric furnace in the smaller sizes for red brass, nickel alloy, and white metal melting is gradually increasing.

FURNACES OPERATING AT TEMPERATURES ABOVE 1,000°F.

Heat Treatment.—It is probably in this field that the use of electric heat is making its most rapid strides to-day. Normalising, ageing, annealing (iron, steel, copper, brass, aluminium, etc.), carburising, hardening, tempering, forging, and heat treating of high-speed steels are all individual processes, and in many cases the product before completion must pass through several of these processes. Modern-day production and competition, accompanied by maximum quality and uniformity of product, have been allies to the use of electric heat for these applications.

The use of the metallic ribbon or rod type resistance furnace in this field is limited for practical purposes to temperatures of 1,800 to 2,000°F., as above these temperatures the deterioration of ribbon or rod is very rapid. Above these temperatures it is necessary to utilise granular carbon resistance or composition rod resistances.

The use of electric heat at 1,000°F. for ageing iron castings has

eliminated the storing of castings for long periods to equalise strains and create a condition of equilibrium before machining, for if machined first and allowed to age afterwards it would subsequently be found that as the strains were relieved a certain amount of warpage or distortion had occurred during the process.

Normalising is the term applied to a process, the purpose of which is refinement of grain structure in steel castings prior to heat treatment. This treatment at 1,600° to 1,700°F. refines the structure of the metal and alters the state of certain ingredients, so that with subsequent quenching or hardening and drawing, maximum uniformity of strength and temper is secured.

All castings which are to be machined must first be annealed or softened to improve their machinability. This requires heating the castings to temperatures ranging from 1,400°F. for iron to as high as 1,900°F. for manganese steel, after which the metal is slowly cooled to normal temperature. When steel is made into forgings, cold rolled into sheets or strips, or drawn into wire, the working of the metal imparts a certain amount of hardness which must be removed by annealing before subjecting the material to subsequent operations.

Until about eight years ago all commercial annealing was carried on in fuel-fired furnaces using coal, coke, oil, or gas, and these methods are still in quite general use. However, in the past few years there has developed in the metal-working industries a recognition of more accurate and uniform heat treatment of metal, including annealing, ageing, and normalising. The tendency is now, where maximum quality and uniformity of product are desired, to give consideration to the electric furnace. The actual cost of the electric energy used will in some instances be higher than the bare cost of fuel would be, but this is frequently justified by the results secured. In general, the electric furnace gives better and more uniform product with less loss from scale and often savings are realised which result in a lower overall cost of the product. In many cases it is essential that the work be kept free from scale, necessitating the packing of steel in annealing boxes before loading into the general type of fuel-fired furnace. These boxes have comparatively short life and are an item of expense. The characteristics of the electric furnace permit of a construction and method of loading which result in the furnace itself serving as the annealing box or container. (See Fig. 2.)

Usually the annealing process may be carried on at night, which permits the use of off-peak power, purchased at minimum cost. Night operation does not require night labour or attendance, because the furnace may be charged in the day, after which the power is turned on in the evening by time switch, which subsequently shuts off the furnace at the end of a predetermined time. The charge is removed in the morning when the men have returned to work. Often the same furnace is used during the day for other heat-treating operations.

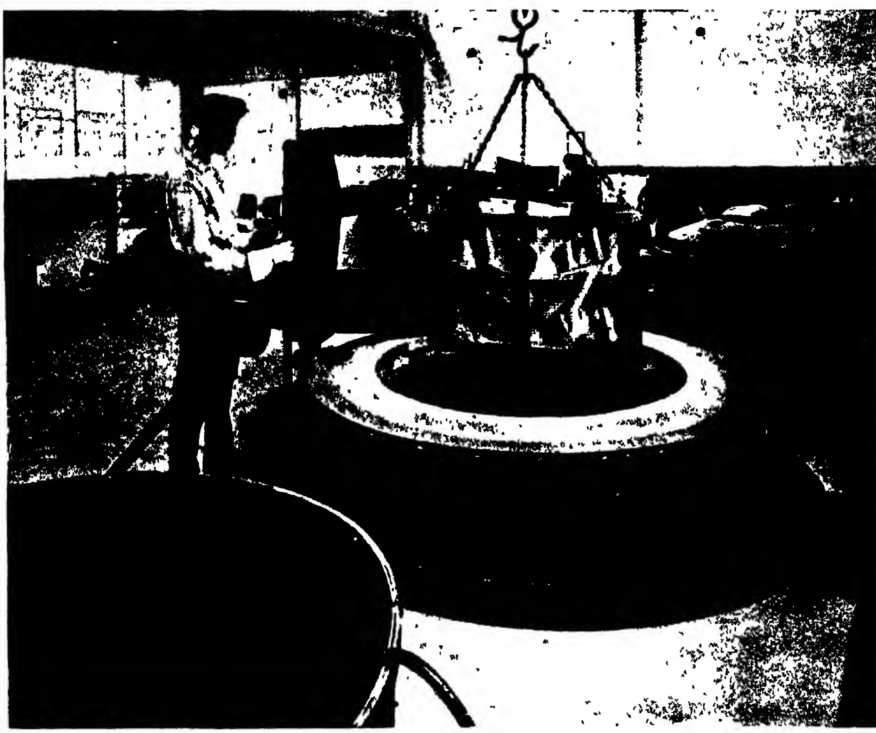


Fig. 2. Pit type furnace for annealing aluminium.

Carburising is the process of coating the wearing surface of the steel with a high carbon case, which, when heated and quenched, develops a glass hard surface, permitting it to withstand excessive wear. In the process of carburising three variables exist, and the quality of work depends upon the range within which each is controlled. These variables are temperature and uniformity of temperature throughout the hearth, time cycle and carburising compound. If two of these can be controlled, the third lends itself to correction. With electric furnaces two of the variables,

namely, temperature with uniformity of temperature throughout the hearth, and the time cycle can be controlled, which leaves the third variable, the carburising compound, for correction. Using the electric furnace, once the correct temperature and time cycle is established for a given piece of work, duplication of results is assured. This is borne out in practice by the fact that constant sampling and use of test pieces are no longer necessary. Further, the absence of contaminating gases, high-temperature gradient and non-uniformity of temperature results in an increased box life.

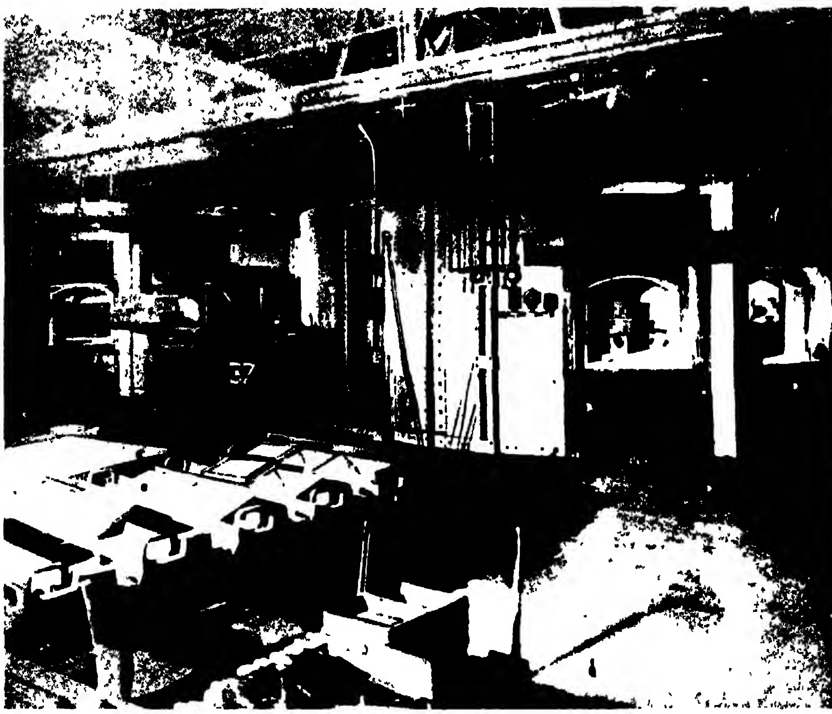


Fig 3. Two furnaces for carburising automobile parts. Each furnace 5 ft. wide, 27 ft outside diameter, 3 ft high with connected load of 500 kW.

Hardening is the process of producing a steel of exceptional hardness on the outside and of maximum toughness on the inside. The material to be hardened is heated in a furnace to just above the critical temperature, and then it is quickly quenched in either oil, water, brine, or molten lead, at various temperatures to attain whatever degree of hardness is desired.

After hardening, tools made from tool steel are usually file-hardened, and there are present many unrelieved strains which tend to produce breakage when the tools are exposed to the

conditions of service. To relieve these strains and thereby give the tool greater toughness, it is heated to a relatively low temperature and allowed to cool. This is known as tempering or drawing.

In both hardening and tempering the cost of the heat is relatively unimportant. Flexibility, accuracy of temperature control, the ability to reproduce given results and the elimination of spoilage, are the vital factors affecting quality of product, and these factors determine overall costs. For these reasons the electric furnace has found popularity for this work.

Fig. 4. One of six electric furnaces for vitreous enamelling refrigerator linings. Connected load of each furnace 250 kW.

The use of electric heat for forging is just beginning. In one large automobile plant there is a line of thirty furnaces being utilised for this work with very satisfactory results. Several companies are experimenting with forging furnaces, and indications are at the present time that the application of electric heat for this process will be most successful.

Vitreous Enamelling.—Vitreous enamelling is the name applied

to the process of fusing low melting glassy mixtures to metals. The electric furnace is widely used in this work for such products as bath tubs, sinks, bathroom fixtures, electric signs, lighting fixtures, refrigerator linings, etc. In most cases, after the installation of the original furnace, additional furnaces have been found desirable and necessary.

Ovens Operating at Temperatures up to 1,000°F.

At the present time there are far more kilowatts of capacity installed in ovens than in furnaces for heat treatment and vitreous enamelling. Possibly this is due to the earlier application of electric heat for processes utilising ovens, more concentrated

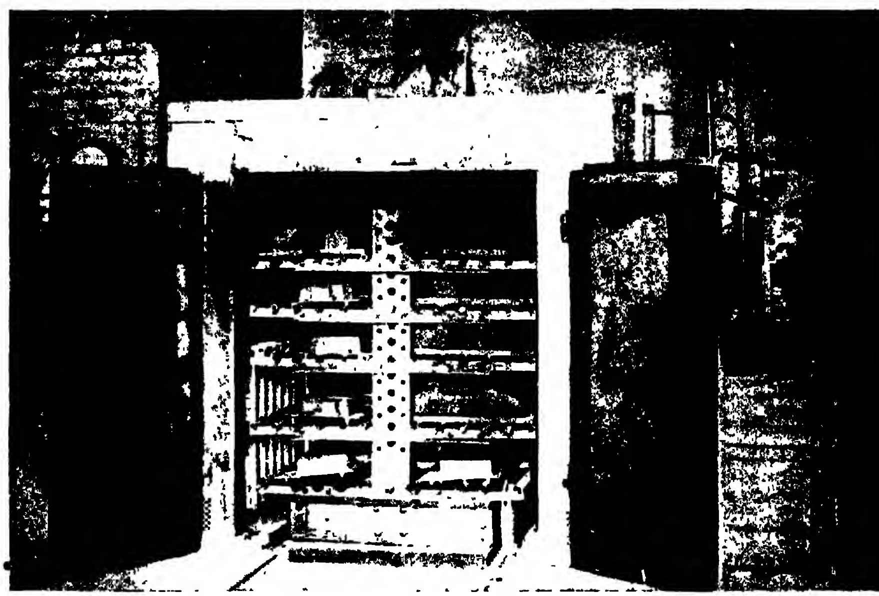


Fig. 5. Box type core baking oven, 6 ft wide, 8 ft. long, 6 ft. high. Connected load 65 kW. Operating temperature 450°F.

activity in promoting electric heat in this field some years ago and the multitude of applications.

In the baking of enamel or japanning, particularly on a production basis, electric heat has been found most successful. In one automobile plant alone there is at the present time approximately 8,000 kW. installed. In some of the very early installations problems of adequate ventilation without wasting considerable heat were encountered, but these were solved after a little research followed by the rapid advance in the use of electricity for

this work. The use of the electric oven for baking of enamel is not confined, however, to the automobile industry, but has spread to other products, such as cameras, typewriters, cash registers, sewing machines, dental equipment, doors and interior trim, utensils, etc., even to buttons and carpet tacks. In many installations recuperative type ovens are used, thus increasing the efficiency of the process.

The use of electric heat for core baking, glass annealing, firing of decorative glassware, bread and cracker baking, toasting cereals,

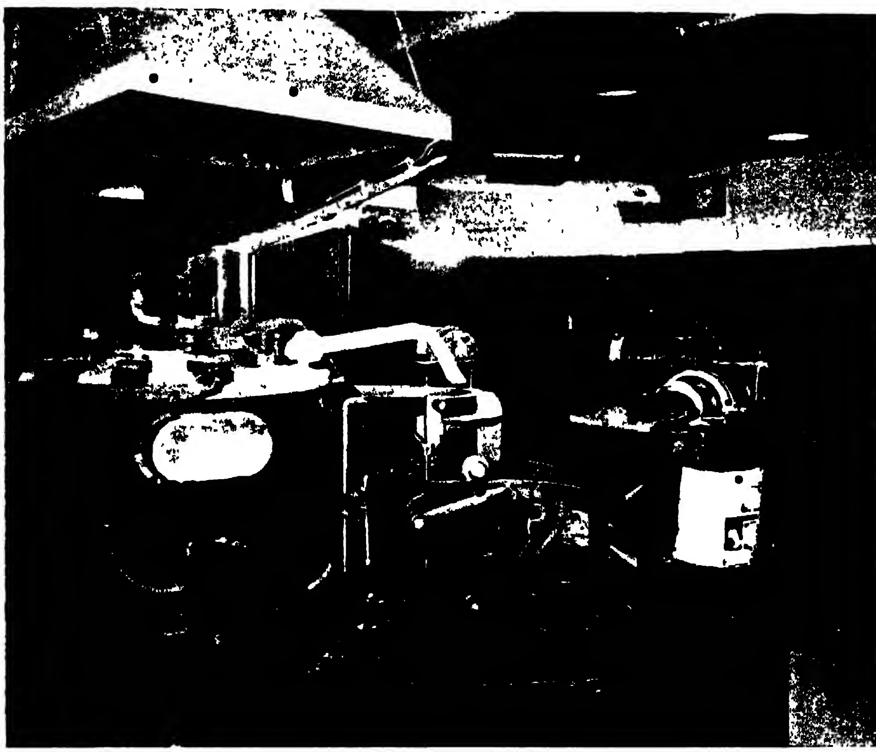


Fig. 6 Electric stereotype pot in a newspaper office.

sherardising, galvanising, roasting, shoe conditioning, paint drying, and in many other processes too numerous to mention, has been found successful and economical.

COMMERCIAL COOKING AND BAKING

The field of commercial cooking and baking is at the present time in its infancy. Many installations have been made in large hotels, country clubs, city clubs, hospitals, sanatoria, and large

bakehouses, and to-day electric heat is gradually being adopted by the restaurants to a much greater extent than for simple toasters and coffee urns. Teste have proved conclusively that there is less meat shrinkage when cooked electrically than any other way. Some claim that in bread baking less dough is required to produce a given weight loaf when electrically baked, although this point is questioned by others. All authorities, however, concede that electricity will bake as good, if not a better, loaf than any other fuel.

Within the past two years the electric travelling oven has gained considerable impetus, and many of the large baking firms have or are contemplating trial installations, while a few have given repeat orders.

Small Unit Applications

The use of small units, such as cartridge units, immersion heaters, space heaters, clamp-on heaters, and standard small units, has a wide application, and many appliances have been standardised, utilising such equipment. Chickens are brooded electrically, as well as the eggs hatched with electric heat. Fox farmers take the chill off the breeder coops electrically, thereby saving loss of life of the pups. A silk stocking manufacturer found by heating the thread the saving in rejects paid for the electricity many times over. Isolated pumping houses and watchmen's houses are heated with space heaters. The newspapers use electricity for monotype pots, linotype pots, and stereotype pots, with vastly improved working conditions. One could continue for some time enumerating interesting applications.

Electric Welding and Rivet Heating

The art of electric welding is filling an indispensable place in modern industry. From an emergency repair tool it has become one of the valuable resources of designers and manufacturers, permitting the use of wrought steel parts having the advantage of maximum strength and reliability with minimum weight, to such an extent that hardly a branch of manufacturing is conducted at the present time but what has taken advantage of welding to produce a superior product.

In addition to the old type of forge welding there have been

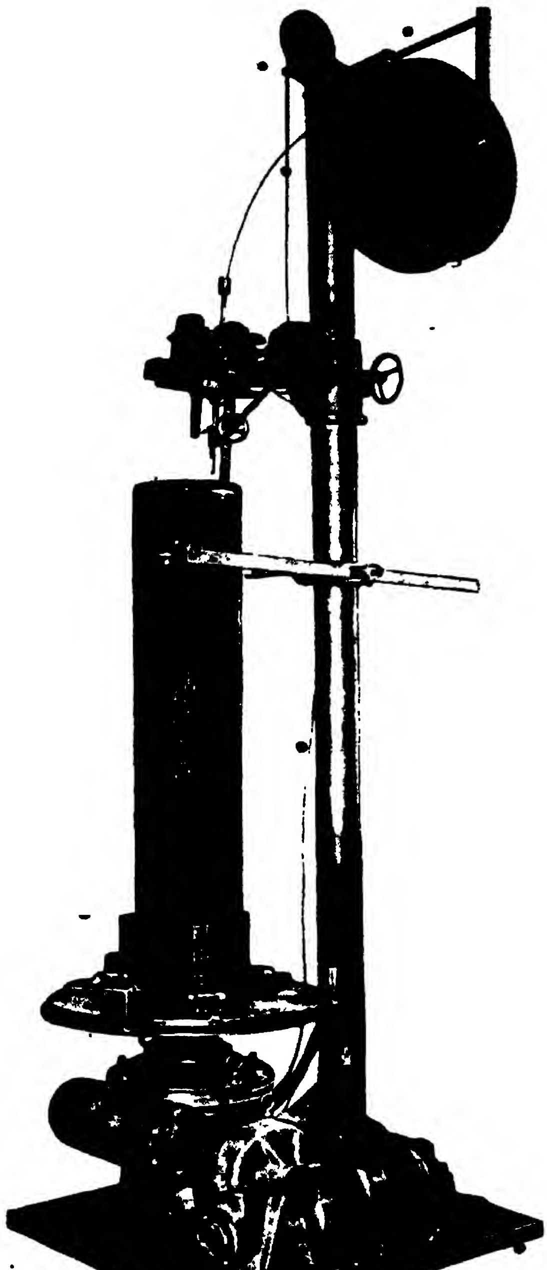


Fig. 7. Circular seam welder.

developed in comparatively recent years several methods of welding, including (1) the electric arc, (2) the resistance process, (3) the atomic hydrogen process, (4) the oxy-acetylene process, and (5) the thermit process:

Spot welders, butt welders, and seam welders have been specially designed for production work, saving their cost many times over.

Recently, there has been some progress made in entirely welded frames for buildings and bridges, and who knows but possibly this may extend to the large office buildings.

Electric Boilers

Electric boilers have been used rather extensively in territories where considerable hydro-electric power is available, and opportunities offer themselves for producing steam at night, when the electric system load curve has a valley; in other words, in locations where the cost of electric service taken at night compares favourably with the cost of coal or other fuel. One electric system in Canada has a load of approximately 80,000 kW. in electric boilers connected to the system.

Electric boilers in small sizes find application in individual cases where the cost of the service is considered secondary to the convenience resulting.

Heat Application in Electro-Chemical and Electro-Metallurgical Processes

This application of electric heat covers a large field, and, it is understood, will be dealt with in another paper. It is mentioned here simply to round off the list of uses of electric heat, so that it may not be overlooked.

In conclusion, the writer may be permitted to repeat that almost every industrial plant offers possibilities for the application of electric heat. Present knowledge does not permit any accurately defined limits in the field wherein electric heating service may be successfully applied to the needs of the industry. The constant improvement in electric heating equipment and the growth of knowledge regarding its use, combined with the steadily decreasing cost of electric service, make it impossible to say with assurance that any industrial process may be safely regarded as definitely and finally outside the field.

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RÉSUMÉ

L'emploi de l'electricité pour le chauffage dans l'industrie est depuis longtemps au delà de l'état expérimental. L'electricité s'emploie avec succès aux buts suivants : à la fusion des métaux, au chauffage des métaux, à l'émaillage vitré, au vernissage, à la cuite, a la recuite, au sechage et à d'autres opérations semblables; dans les boulangeries, restaurants, etc.; au soudage et au chauffage de rivets; dans les chaudières et dans les procédés électrochimiques et électrométallurgiques. La consommation de chauffage électrique industriel aux États-Unis s'évalue à plus de 2.000.000 de kilowatts.

Malgré le prix relativement élevé par unité du chauffage de cette espèce, l'emploi de l'électricité pour le chauffage industriel résulte principalement des avantages inhérents à la méthode. Parmi ces avantages sont à énumérer un meilleur contrôle de la température et une meilleure distribution de la chaleur, dont les résultats sont une plus grande uniformité du produit et une économie dans l'échantillonnage et dans les rejets. L'emploi d'appareils économisant la main-d'œuvre ou le placement d'appareils de chauffage dans la ligne de production a éte rendu possible

grâce à l'économie qui en résulte. De meilleures conditions de travail quant au chauffage et à la propreté donnent de meilleures conditions générales. Le risque d'incendie diminue et les taux d'assurance peuvent être baissés. Il y a d'autres avantages dans les applications spéciales.

On ne peut pas à présent prévoir l'essor de l'emploi futur de l'électricité au chauffage industriel. Le perfectionnement des appareils et la connaissance approfondie des méthodes de son emploi, aussi bien que la diminution du prix de l'énergie électrique, en font constamment croitre le champ d'application Une charge de 47.000.000 kW. disponible aux États-Unis pour les buts industriels a été indiquée par une étude faite en 1926. D'après cette base, seulement quatre pour cent des possibilités auraient été développées.

PRODUCTION AND UTILISATION OF PRODUCER GAS IN INDUSTRY

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

WM. B. CHAPMAN

*Paper No. K*19

CONTENTS

DIFFERENCE BETWEEN AMERICAN AND EUROPEAN GAS PRODUCER PRACTICE

American gas producer practice differs from European in two essential respects: American producers are operated at a faster rate and the upper portion of the fire-bed receives more agitation. A third difference, which the author believes to be regrettable, is that until quite recently water-jacketed gas producers have not been looked upon with favour in the United States, while in Europe the water-jacket has been accepted for many years.

Possibly we should add a fourth point of difference and state that less attention has been paid in the United States to saving fuel in gas producers by improving the quality of the gas. However, the higher price of coal during and since the War has forced managers out of their former complacency regarding gas producer losses, and good progress is now being made, especially in regard to the use of modern automatic controlling devices.

Points of difference in gas producer design and practice indicate

progress. They also indicate that the gas producer art is far from being standardised—for nothing is ever standardised until a fair measure of perfection has been attained. Nevertheless, the mechanical gas producer in the United States superseded the hand-operated producer long ago. During the past eighteen years my company has sold but one order of hand-operated gas producers, and we doubt if the other builders of gas producers in the United States have sold more. The automatic, mechanical producer is the only type that has been acceptable since 1910.

The purpose of this paper is to point out the lines of progress in gas producer design and application which the author believes to be most significant. It also discusses hindrances to future progress, and suggests remedies which the author believes will ultimately be effective.

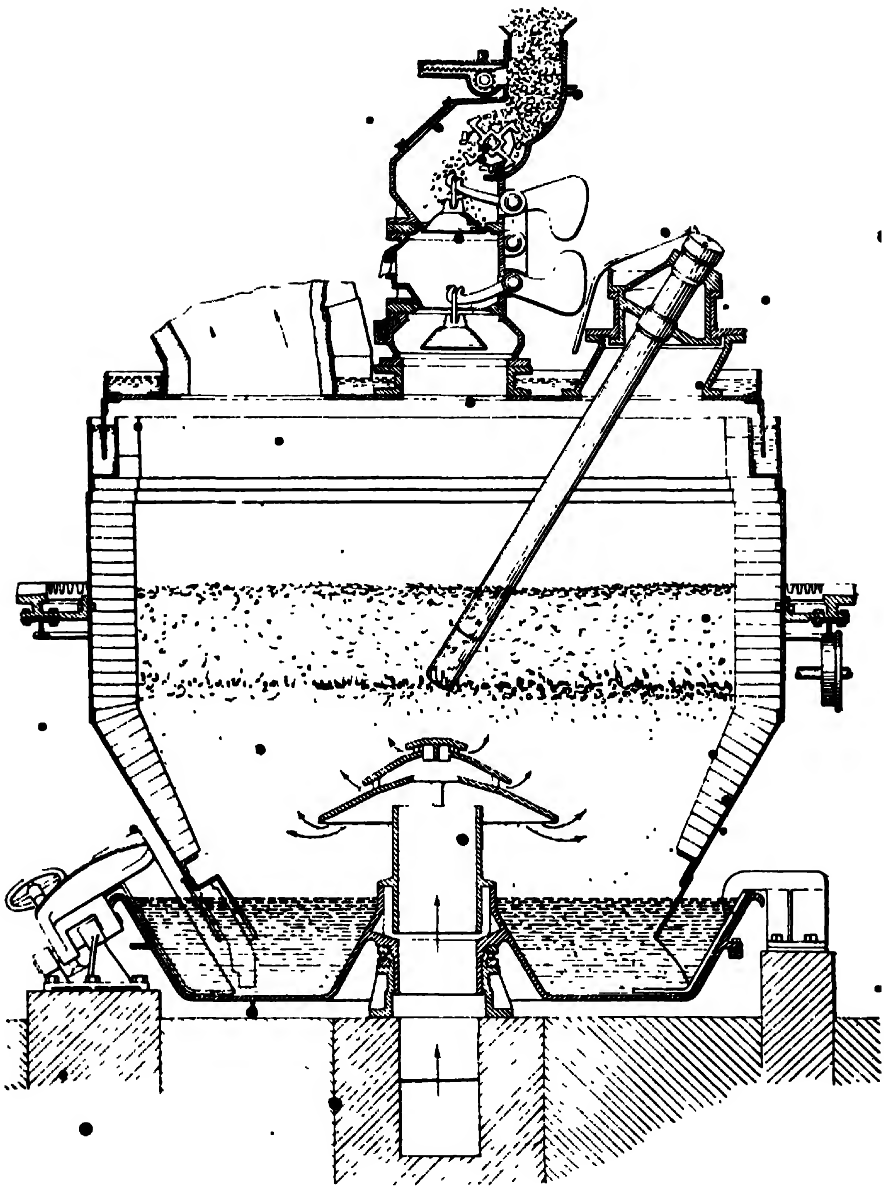
Producer Capacity

First, let us take up the important question of capacity. The rate at which producers can be operated without hand-poking is a fair indication of their comparative value. The standard size of gas producer in the United States is 10 ft. internal diameter, which makes the outside diameter about as large as can be shipped in one piece on American railroads. The capacity of the old hand-poked producer was about ten 2,000-lb. tons per day of twenty-four hours. The first successful mechanical producer (the Hughes) increased this to eighteen tons.

A good working capacity for any of the four mechanical producers now on the American market for heating industrial furnaces is 36 tons a day, using almost any kind of bituminous coal, except slack; and if the coal has an ash with a high fusing point, 48 tons a day is now the common practice. The writer, in experimenting during the past three years with special types of producers having more uniform, more complete and faster agitation, has been able to gasify 100 tons a day without any hand-poking, while maintaining the CO_2 content of the gas between 5 per cent. and 6 per cent. He therefore believes that producers of larger capacities, costing much less per ton of output, will be available before long.

Fire-Bed Requirements

The "mechanical features" of a gas producer are primarily for the purpose of producing and maintaining good gas-making conditions



WELLMAN-SEAVER-MORGAN PRODUCER

Fig. 1. Wellman-Seaver-Morgan Producer.

The stirring finger which reaches to within a few inches of the bottom of the firebed swings back and forth from the centre to the wall, while the producer walls and fire-bed revolve normally at the rate of 1 rev. in 10 min. The makers of this producer are the chief exponents of "vertical agitation." The revolving fire-bed causes the pan (which has no driving mechanism) to revolve, the rate being regulated by an automatic locking and releasing device.

in the fire-bed. The saving of an army of gas makers, although important, is secondary to the obtaining of a reliable, uniform gas at all times, and its resultant saving of fuel. In a general way we know that our objective is to obtain "good gas-making conditions in the fire-bed." Not every mechanical motion or type of agitation that is easy to devise for a fire-bed is of equal benefit. Some types of agitation have even proved detrimental. The author believes that the most important requirement of a gas producer fire-bed can be expressed in two words—*horizontal uniformity*.

Any horizontal plane taken across a gas producer fire-bed should be uniform throughout in two important particulars—density and temperature. Of course, no two horizontal planes taken at different heights should or could be alike, but each individual horizontal cross section should be as nearly uniform as possible in density and temperature. All other requirements for gas producer fire-beds, except the obvious one of a very hot hot-zone, are secondary and coincidental to the obtaining of the ultimate objective—horizontal uniformity in respect to density and temperature.

THE BEST FORM OF AGITATION

Having the above objective in mind, we can formulate a rule for evaluating the merits of various suggested mechanisms for benefitting gas producer fire-beds. The rule is this: "That type of producer is best which enables one most easily to attain the greatest degree of horizontal uniformity in the fire-bed.". Conversely: "That type is worst which makes it most difficult to attain horizontal uniformity." The gas-making art will progress more rapidly when we all understand and apply this simple rule for determining the merits of different kinds of mechanisms advocated for manipulating fire-beds. The author is convinced that two horizontal water-cooled members, one operating at the top of the fire-bed and the other in the ashes just beneath the fire-bed (Fig. 2), offer the most logical and efficient mechanical solution to the problem of obtaining horizontal uniformity in gas producer fire-beds.

Surface Agitation.—In regard to agitating the upper portion of the fire-bed, most American bituminous coals have a greater tendency to cake than European coals; hence, all four of the leading makes of gas producers in the United States provide a considerable amount of surface agitation, but only two of them provide much agitation from beneath. The author is of the opinion that European engineers are wrong in neglecting to agitate the surface of gas

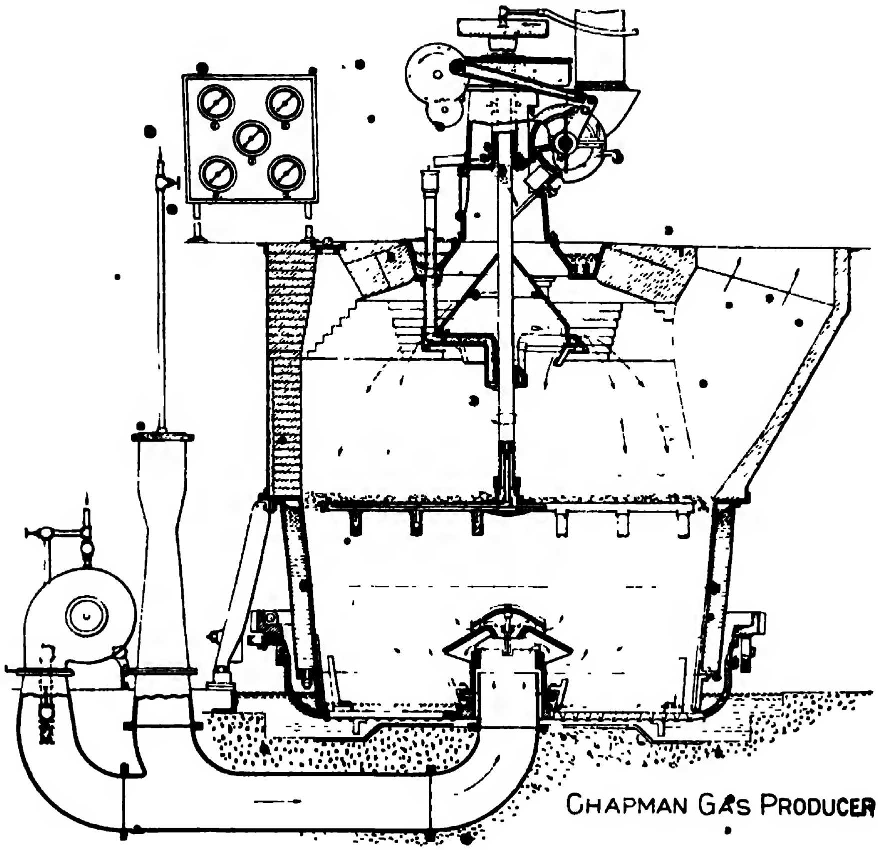


Fig 2 Chapman Gas Producer

This producer has separate agitating members for the top and bottom of the fire-bed, which operate horizontally The top agitator automatically varies in height to agree with the top of the fire-bed and normally revolves at 7 r.p.h The tuyere hood and the agitator in the ash-bed revolve together, normally at 1 rev in two hours. The makers of this producer are the chief exponents in the U S of "horizontal agitation." They also advocate cooled walls.

producer fire-beds. The writer's company has frequently added its Floating Agitator to various standard European makes of gas producers having only bottom agitation, and thereby increased the capacity 60 per cent. or more, while at the same time improving the quality of the gas very materially.

The following is an average of several typical tests that have been sent us from Europe during the past ten years. Some of the reports received, however, were so much better than the others that we questioned their accuracy and did not use them. The fuel used was bituminous coal. In some cases the ash content was high, in others it was low.

Capacity	Tons per 24 hrs.	Lb. per sq. ft. per hr.
Without floating agitator ...	19.5	23.2
With floating agitator ...	32.6	38.7

Average Analysis	CO_2	O_2	CO	H_2	CH_4	N_2	Net Calorific Value B.Th.U.
Without floating agitator ...	8.9	0.1	21.7	13.9	2.6	52.8	131.6
With floating agitator ...	5.3	0.1	25.8	14.5	2.6	51.7	146.4

Increase in capacity 67 per cent. Increase in heat value 11 per cent.

Bottom Agitation.—Agitating the bottom of the fire-bed has been neglected in the United States, although it is just as important as agitating the top. It can easily be overdone and thus destroy good gas-making conditions in the fire-bed. This is particularly true when using fine fuels, or any fuel that gives a thin hot-zone. Nevertheless, proper agitation of the bottom of the firebed usually doubles the capacity of the producer, and should never be neglected.

Complete Agitation.—During the past twenty-five years the author has operated about twenty-five different types of mechanical gas producers. Some have agitated only the top of the fire-bed, some only the bottom, and some only the middle; also four have been of the underfeed type and two have used pulverised coal. It is his conclusion that if bituminous coal is used the agitation should extend throughout the fire-bed from top to bottom, and also throughout the ash-bed. The top should be agitated frequently and thoroughly. Complete agitation of the upper portion of the fire-bed every three minutes is not too often for maximum capacity, while once in ten minutes is adequate for minimum capacity. The agitation should gradually diminish from the top to the bottom. If a horizontal water-cooled beam is used for agitating the bottom of the fire-bed, it should make about three revolutions per hour for maximum capacity and one revolution in three hours for minimum capacity.

The question of the form or type of agitation employed is very important. Much money and effort have been wasted in trying to develop forms of agitation that obviously could never contribute much toward horizontal uniformity in the fire-bed. If we are going to progress we must think in terms of what the fire-bed requires rather than in terms of what is easy to do mechanically.

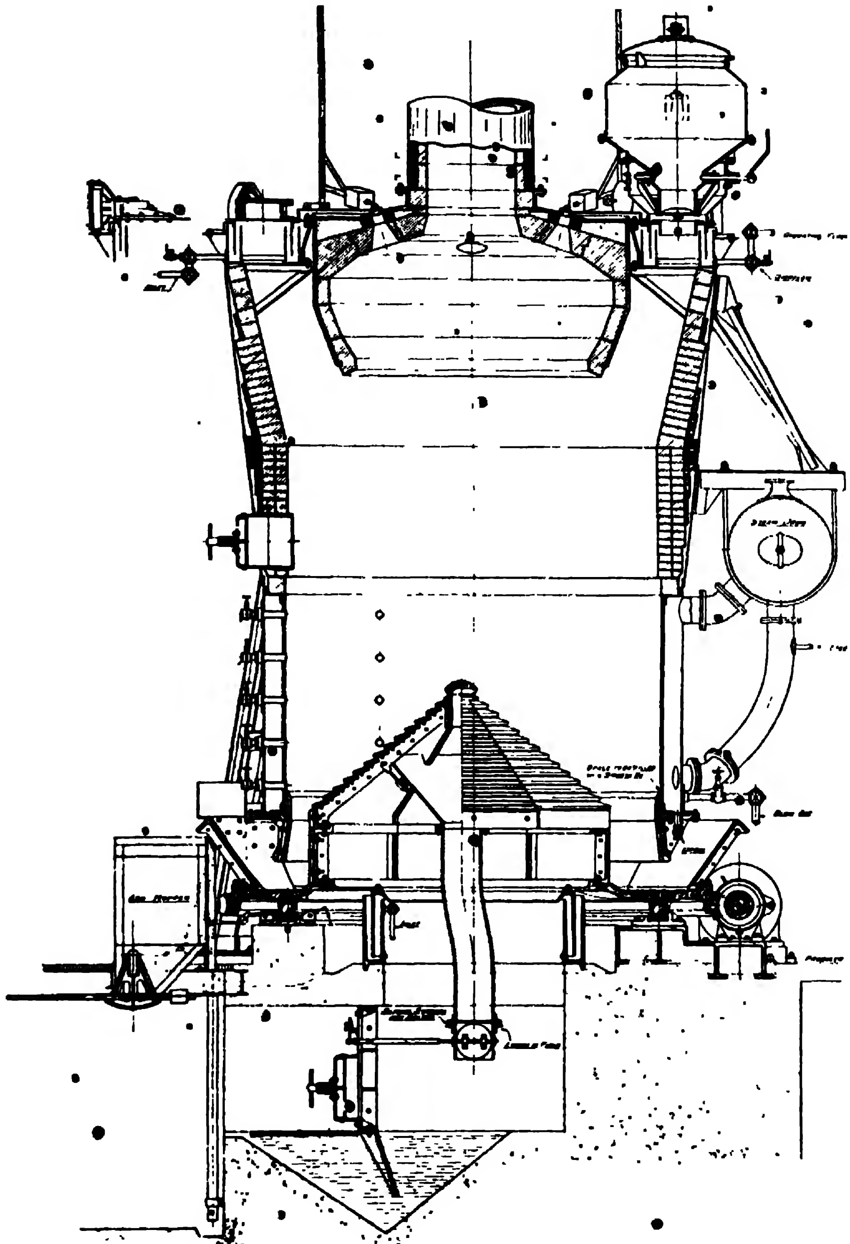


Fig. 3. U.G.I.—Kerpely Producer.

The annular space surrounding the gas outlet is kept filled with coke. The annular opening in the top for feeding is continuous and is closed by an annular cover having a water seal on each side. The fuel hopper is attached to, and revolves with, the cover. This producer handles 1½ tons of coke per hour, averaging less than ½ in. in size and containing 40 per cent. breeze, and makes a uniform gas of about 125 B.Th.U.

Water-Jacketed Walls

In regard to the use of water jackets, the author believes that practically all grades of coals can be gasified more satisfactorily if the producers have either water-cooled or air-cooled walls surrounding the hot-zone. While it is unquestionably true that a water-cooled steel wall ⅜ in. thick chills the fire-bed to a degree that is detrimental, it is not true that the chilling would be detrimental if the water-cooled shell were made three times as thick. One American make of gas producer has a water-cooled shell made of steel plate 1 in. thick. It formerly was ⅜ in. thick, and considerable trouble was experienced because of the excessive chilling of the fire next to the cold wall. The thickness of the steel was increased to 1 in., whereupon the trouble ceased and the quality of the gas became satisfactory. Another American make of gas producer has a refractory lining 4½ in. thick (instead of the conventional 9 in.), with a water jacket at the back of it. It is rather expensive, but fairly effective in preventing clinkers from adhering to the walls. The author has experimented with a cast-steel water-cooled shell and found it especially valuable in gasifying poor grades of fuel.

Producer Lining

Until recently, gas producer manufacturers have usually provided or specified second-quality firebrick for lining their producers. This is all right for everything but the hot-zone, and all wrong for the hot-zone. It does not seem to be generally known that if the walls surrounding the hot-zone are made of an extra good refractory that won't get sticky, the molten ash will not adhere strongly to it —provided the added precaution is taken of having the material extra fine ground and extra hard pressed. A good weld cannot be obtained between two pieces of steel unless both are hot enough to be "sticky"; the same principle applies to the "welding" of clinkers to a refractory wall. If the hot-zone instead of being water-cooled is to have a refractory lining, the author recommends a special 9 in.×9 in. block 4½ in. thick, made of best grade firebrick, extra fine ground and extra hard pressed. These blocks should be on a circle 10 ft. internal diameter, and have either a refractory lining at the back of them made of second-class firebrick, or an air jacket.

The walls of gas producers are the chief cause of the blow-holes and their resulting clinkers, for they are continually retarding the even down-flow of the fuel and thus disrupting the fire-bed. More

attention should be paid to the design of the walls and also to the question of stroking the fuel outward by an agitating member to close the loose places.

IMPROVED PRODUCERS WILL ENLARGE THE PRODUCER GAS FIELD

Producer gas should compete more successfully with fuel oil and coke-oven gas than at present, because it is essentially cheaper. Also producer gas should compete with solid fuel burnt upon a grate for heating boilers, because gas can be burned more efficiently and controlled more readily than any mechanically-stoked fire-bed. Furthermore, producer gas has most of the advantages of pulverised coal, without its disadvantages. However, before producer gas can come into its own and become popular for many other purposes than the heating of large industrial furnaces, considerable progress must be made in developing a better gas producer. Several promising developments are well under way, and the results are most encouraging.

GAS PRODUCERS SHOULD USE THE CHEAPEST FUEL

Gas producers should be able to use the cheapest fuel known—slack bituminous coal. The author knows of no producer that is gasifying slack coal satisfactorily to-day. Our present producers are limited for best results to crushed lump-coal or a good grade of run-of-mine properly crushed. We must overcome this limitation. If fine fuel, such as slack, is dropped from above upon a producer fire-bed operating at high capacity, an objectionable quantity of coke-dust will be carried out into the gas flue. Hence the fuel must not be dropped from above, it must be fed in laterally or from beneath. Moreover, most of our present agitating means are not designed to prevent blow-holes in a highly-forced fire-bed composed of slack coal. Heretofore the problem of making producer gas from slack coal has looked so formidable that little effort has been made to solve it. We believe that a properly agitated underfeed producer, arranged so that the final flow of the fuel is in opposition to the direction of flow of the incoming blast, will solve the problem. Experiments conducted by the author indicate that the producer problem may also be solved in quite another manner by maintaining fine fuel upon a rising column of air.

Gasifying Washery-Refuse.—During the past year the author has experimented with washery-refuse in a mechanical gas producer operated at an extra high speed. The average size of this refuse was under $\frac{1}{8}$ in. Most of it was dust. It analysed as follows :—

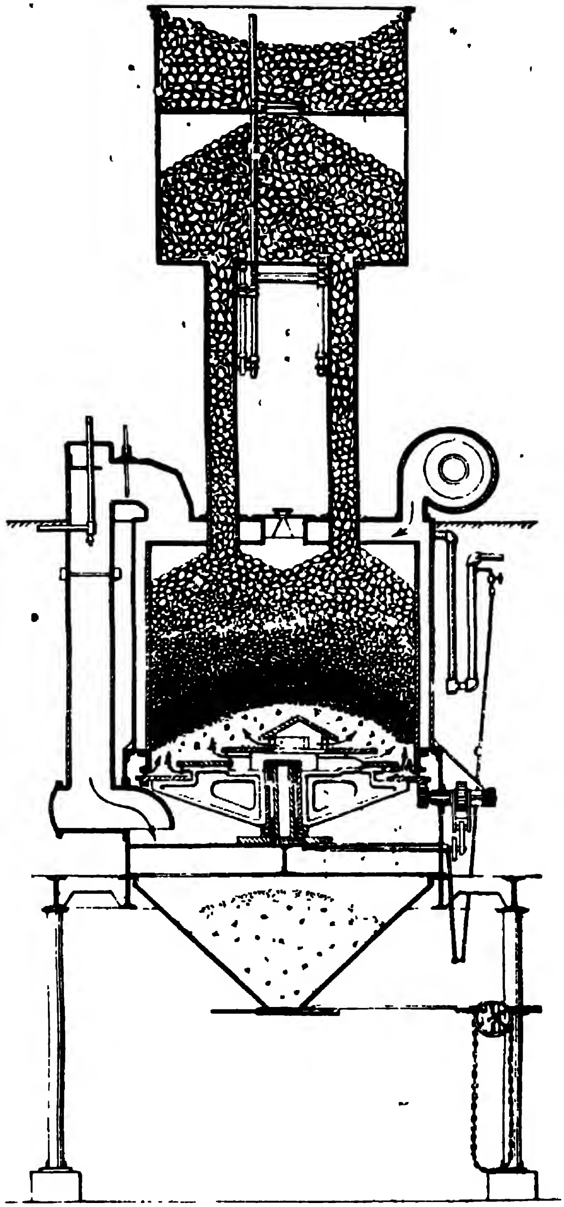


Fig. 4. Dover-Galusha Producer.

A new American producer developed especially for the smallest sizes of anthracite coal. The steps of the revolving grate are located eccentrically and serve to crush the clinkers against the wall, while discharging the ashes inwardly. The automatic feed is non-mechanical. Note the thick bed of fuel, which is possible with anthracite coal or coke.

Moisture	Volatile	Fixed C.	Ash	Sul.	Phos.
11.5	20.5	32.2	56.3	7.1	.045

The experiment was for the purpose of determining how best to get rid of 200 tons a day of this low-grade refuse from the coal washery. The producer was operated on the day shift only, the air blast being shut off at night. We were able to attain an average of 8,424 lb. an hour, which would be equivalent to 101 tons (2,000 lb.) a day. The producer was 10 ft. inside diameter. Some hand-poking had to be done every two hours, but we believe that a modified form of agitation will eliminate the need of poking altogether. No steam was used with the blast, as steam made the fire-bed too cold. The average analysis when operating normally was as follows:—

CO_2	O_2	Ill.	CO	CH_4	H_2	N_2	Net Calorific Value B.Th.U.
11.2	0.1	0.3	5.7	1.1	0.0	81.6	33.8

The gas was burned immediately over the producer fire-bed and allowed to waste. The temperature obtained was about 2,000°F. The waste gases in the stack averaged 17 per cent. to 18 per cent. CO_2.

Various efforts had been made before this experiment to burn the above-mentioned refuse in different types of stokers and also by pulverising it and mixing with ordinary coal, but all attempts failed until the special gas producer was tried. It is now planned to build a new type of mechanical producer, with modified methods of charging and agitating, and locate it directly under a waste heat boiler. The value of the steam made will pay for the new equipment, and the present cost of throwing away the refuse, which now amounts to 75 cents a ton, will be saved.

Other Experiments.—The foregoing experiment is the third within a period of three years in which the author has been able to gasify over 100 lb. of fuel per sq. ft. per hour. In each case an unusual amount of agitation was provided and a blower of unusual capacity was used. In one case the producer was water-jacketed, in another it was partially water-jacketed, while in the third there was no water-jacket at all The producer having no water-jacket was the only one which required an excessive amount of hand-poking.

In one of the above experiments coke was used satisfactorily. It was found that when coke breeze was substituted for coke, the capacity was reduced from 100 tons to 75 tons a day and the quality of the gas was somewhat impaired. Further details of the

foregoing experiments in specially designed mechanical producers are withheld until the author is able to embody them in commercial products. The experiments have not been completed and are not ready for publication. They are mentioned merely to indicate some of the background upon which the author bases his optimistic views regarding the future of producer gas.

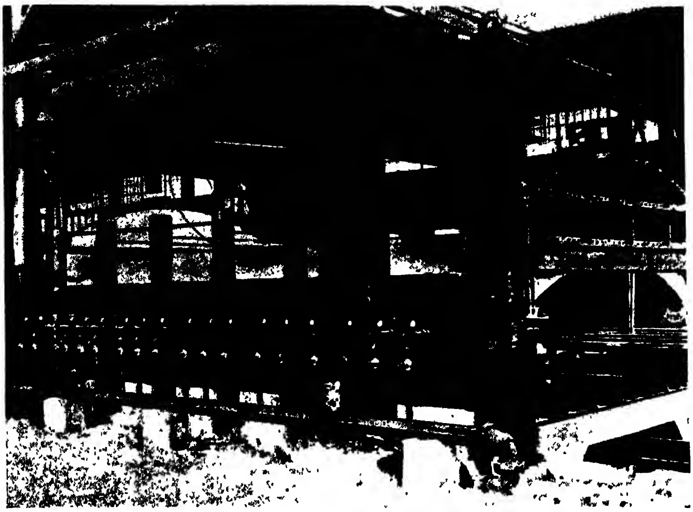
THE SOOT PROBLEM

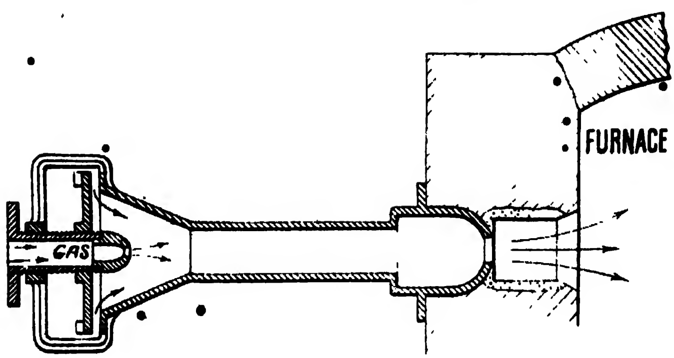
Another shortcoming of our present bituminous coal gas producer is the excessive amount of soot contained in the hot gas leaving the producer. The ABC Vortex Soot Collector is likely to help to solve this difficult problem. Four of these collectors of the unlined type have been in successful operation at the plant of the Ford Motor Co., in Walkerville, Ontario, for over two years. The first collector to have a refractory lining (necessary to keep the gas hot) is now on trial at the works of the American Bottle Co. in Newark, Ohio. This collector is of the cyclone type, but is long and slender; like a true cyclone, instead of short and squat like the conventional so-called cyclone collectors. The pressure drop of the gases going through this new type of collector must be at least 1½ in. of water in order to produce sufficient velocity to obtain the desired results. The extra pressure needed can be obtained with any good steam jet-blower if operating at moderate capacity, or from one of the modern types of turbo-blowers if a large capacity is desired. Complete data are not yet available, but are promised soon. An underfeed producer would also help to solve the soot problem.

BURNING PRODUCER GAS UNDER PRESSURE

In using hot producer gas, a slight pressure at the burner is frequently desirable. Cold producer gas is always used under pressure, as it would not burn well otherwise, but until recently there has been no practical way of inducing pressure in hot producer gas.

A Venturi jet-blower burner, in which cold, washed gas at 10 lb. pressure aspirates the necessary air for combustion, has been developed by the Surface Combustion Co. (Fig. 5). Excellent results are obtained with no preheating of either the air or gas—especially in heating small and moderate sized furnaces. Large regenerative furnaces, designed by Arthur L. Stevens, for heating forgings weighing 100 tons or more, are operating very successfully using cold, rich producer gas under a pound pressure.





SURFACE COMBUSTION Co.
FORGE FURNACE AND BURNER

Fig. 5. Surface Combustion Co. Burner and Furnace.
This burner is of the jet blower type adapted to use clean cold producer gas at 1 to 3 lb. pressure for aspirating cold air. Owing to the high pressure used, a variation in the quantity of gas produces a like variation in the of air.

When the gas and air are both used hot, an ounce pressure is just as effective as a pound pressure when they are used cold. A new type of hot-gas pressure burner (Fig. 6) has recently been developed by the Chapman-Stein Co. It is of the Venturi type and

uses a jet of cold (or moderately warm) air under a few ounces of pressure to aspirate and mix hot, raw producer gas and hot air. Large capacities and a much better control of the furnace are thus obtained. This burner is likely to prove an important contribution to the producer gas art.

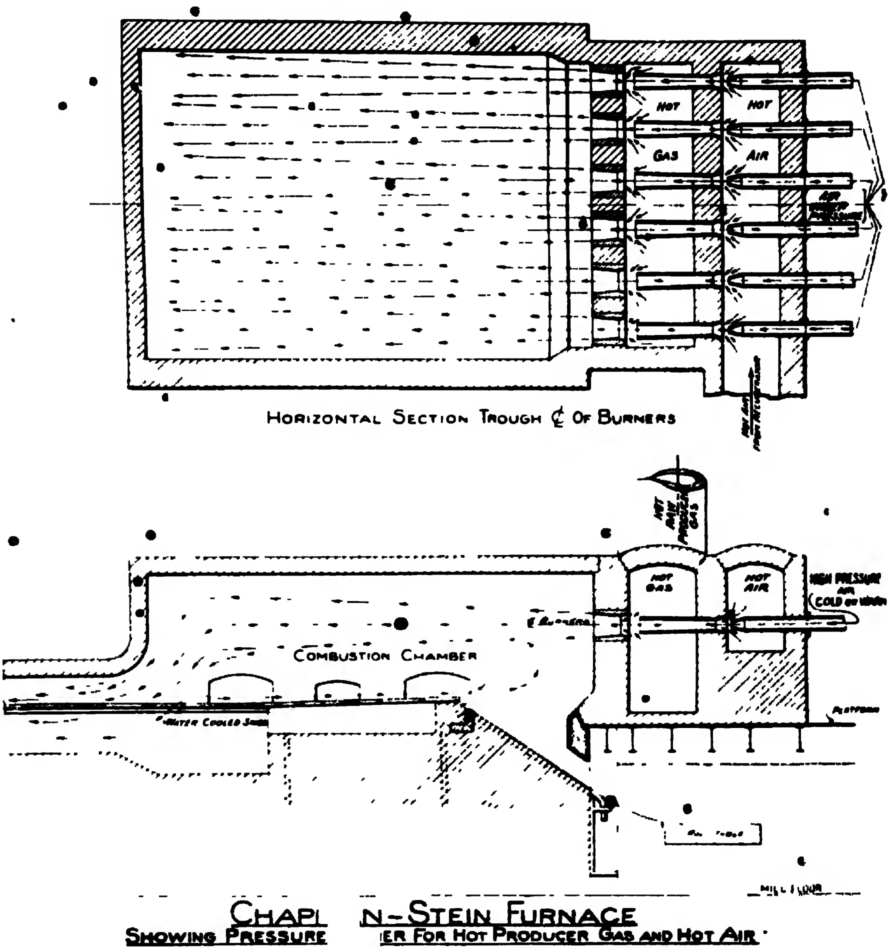


Fig. 6

Producer Gas in Open Hearth Furnaces

A special Venturi Port, designed to give a quick mixture of air and gas, has been developed during the past eight years by the Open Hearth Combustion Co. (Fig. 7). The flame has been increased in temperature and shortened in length, thus increasing the amount of work done at the incoming end of the hearth and decreasing the deterioration at the outgoing port. Although the

throat is smaller than conventional practice, the down-takes are larger, so that no increase in the stack-draught is required.

The small Venturi throat causes a high velocity of the fuel stream and consequently produces a considerable aspirating effect on the

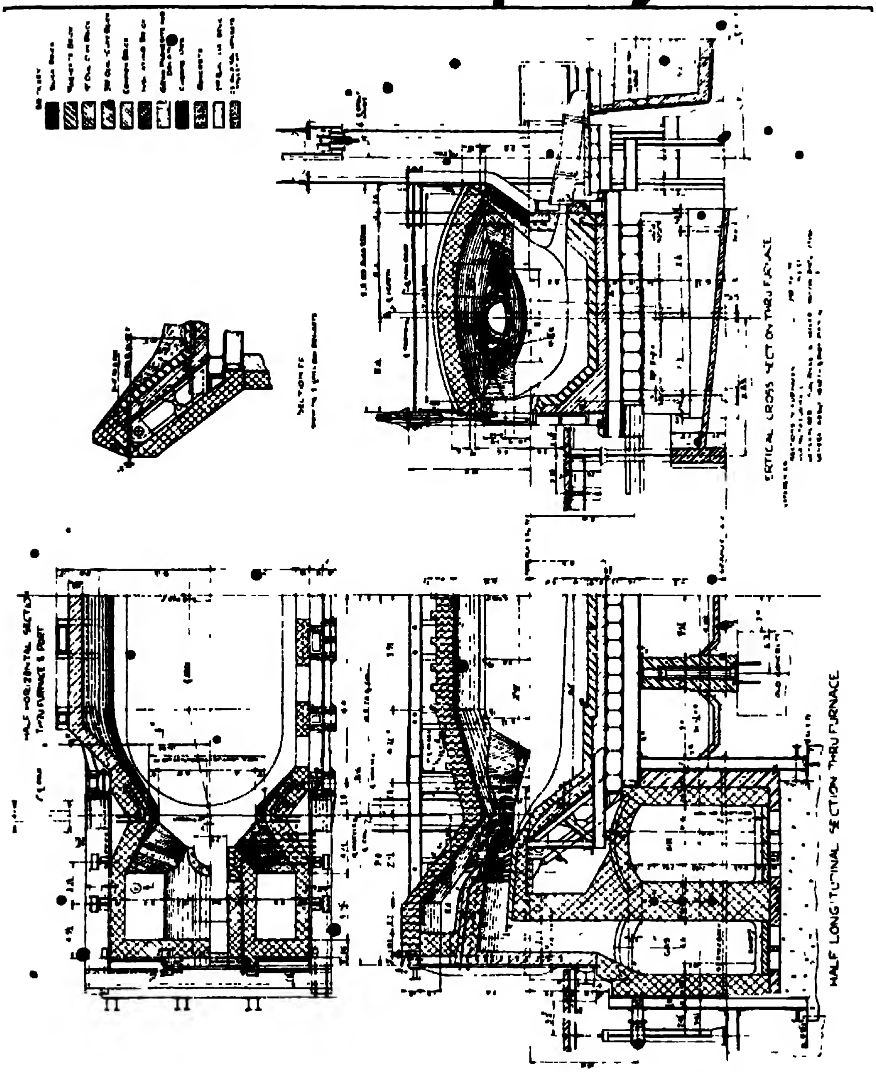


Fig. 7. Open Hearth Combustion Co.'s Furnace.
Showing sloping back wall and Venturi Port.

incoming air, which is of great advantage. The capacity of a furnace can be increased from 10 per cent. to 25 per cent., depending upon the merits of its previous design. At one plant using a large number of Venturi Ports the fuel consumption, including total input of fuel into the gas producers, has averaged over a long

period of time 423 lb. of coal per gross ton of ingots cast, and the furnace life has been 376—102 ton heats on a hearth containing 496 sq. ft., which is very small for such a large charge.

SLOPING BACKWALL FOR OPEN HEARTH FURNACES

During the past five years the same company has developed a sloping backwall for open hearth furnaces (Fig. 7). The inclination of the backwall is such that loose material such as dolomite can be used to maintain the backwall, and the life of same is practically indefinite. It was at first thought that possibly the greater span of the roof might prove detrimental. However, experience has shown that the roof life has been increased.

More than 200 open hearth furnaces in the United States have been changed to incorporate this new type of backwall. It is claimed that the combined saving for both the Venturi Port and sloping backwall amounts to from 50 cents to $1.00 per ton of ingots produced.

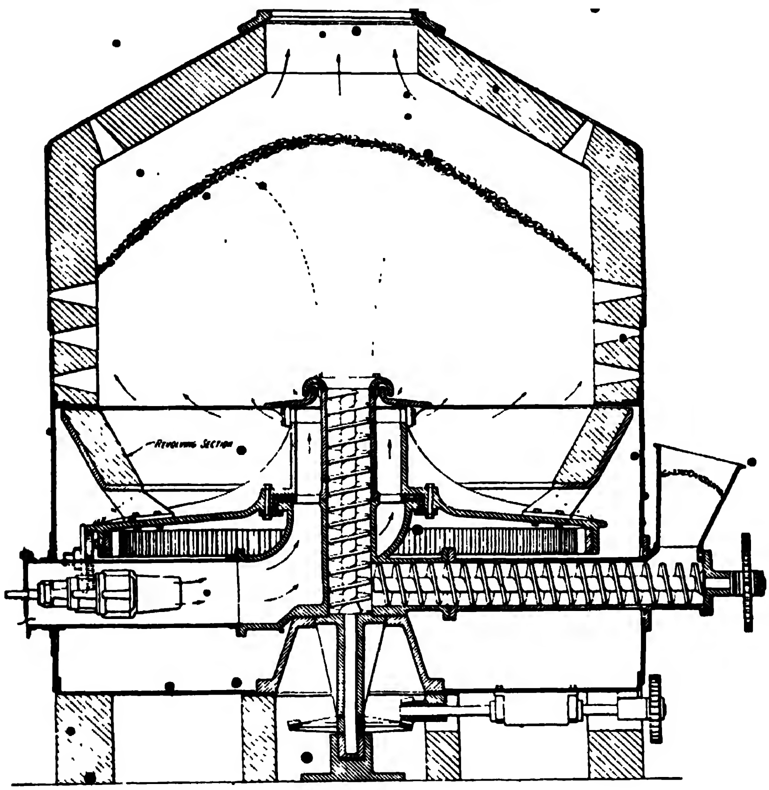
The author believes that the present demand for increased furnace capacities and higher rates of combustion and better furnace control will continue for years to come, and to meet this demand it will be increasingly necessary to supply hot gas and preheated air, both under pressure.

THE FIRE-BED MAY BE MADE TO CLEAN THE GAS

The author believes that the much-desired and long-sought-for clean producer gas, made from bituminous coal, may be obtained in a manner which applies equally well to both hot gas and cold gas. It has long been known that either the down-draught type or the underfed type of fire-bed is effective in converting the higher hydro-carbons into CO and H_2, thus eliminating most of the tar and soot. However, in both of these types of fire-beds the newly charged fuel and the air blast flow in the same direction; the available air is therefore limited where most needed to complete the gasification and final consumption of the fuel. This makes it impossible to gasify all the carbon in the ash without considerable excess air, which would completely destroy the quality of the gas produced. Hence, if the down-draught or the underfeed principle is to be employed it must be combined with, and followed by, counter-flow combustion of fuel and air. The author believes his experience has proven that fire-beds combining the underfeed and counter-flow types will solve the problem, provided they are equipped with suitable mechanical means for keeping them in good gas-making condition.

THE UNDERFEED PRODUCER

Hitherto those who have attempted to develop an underfeed producer have not provided suitable agitation. They have also neglected to provide a final stage for consuming the fixed carbon, in which the fuel and blast flow in opposite directions. Henry Ford came the nearest to solving the problem when in 1914 he built and



GRAY EXPERIMENTAL UNDERFEED GAS PRODUCER

Fig. 8. Gray Experimental Underfeed Gas Producer.

operated a 10-ft. internal diameter underfeed gas producer (Fig. 8) for bituminous coal, invented and designed by his chief engineer, Edward Gray. It operated somewhat on the counter-flow principle, but did not provide adequate agitation. The gas was tar-free, and after washing, was used in a large gas engine. At that time no suitable method of agitation was known, and automatic

controlling devices had not been perfected. An objectionable amount of hand-poking was therefore required. This experiment, like all others undertaken at that time, with which the writer is familiar, was ultimately discontinued, but it was so near success that it was a surprise to all when it was abruptly abandoned. The author believes, however, that with improved agitating means for the lower portion of the fire-bed, it would have succeeded, and slack coal would now be in common use in gas producers.

UNDERFEED PRODUCER GAS.

The underfeed type of producer is just as efficient as the convential top-feed type of producer. The gas produced is higher in CO, but not as rich in hydro-carbons. It is adapted to use in gas engines and industrial furnaces which do not require temperatures above 2,600°F. These furnaces include annealing, forging, and rolling, but do not include steel melting or glass melting, nor do they include welding, unless special burners are provided. Nevertheless, a clean producer gas made from bituminous coal has many applications in industry, and the only real drawback to its general acceptance is the expensive equipment and expensive methods now required for producing it. When a comparatively clean gas is made in the producer it will then be possible to pass the hot gas through a waste heat boiler as it leaves the producer, and thus utilise most of its sensible heat before burning it.

PRODUCER GAS FOR POWER

The thermal efficiency of using producer gas for power is unquestioned, but no gas producer for utilising cheap bituminous coal is available. The use of bituminous coal for gas power has been attempted in various ways, but has never been a practical success; the conditions to be met are too exacting. Producing gas from anthracite coal, however, has been moderately successful for power purposes. Possibly a thousand installations were made during the ten years following the St. Louis Fair, but most of them have now been abandoned. Anthracite, however, is too expensive for large units, and electric power purchased from a central station is more practical for small units. A suitable automatic producer for slack bituminous coal is the key to the situation.

Power from gasoline is about six times as expensive as it would be if it were made from producer gas made from slack bituminous coal, but no such producer power is obtainable to-day. The power developed from a pound of gasoline is about 1.5 H.P. hours. The amount of power obtainable from a pound of low-grade bituminous

coal containing 12,000 B.T.U. per pound is about 1.1 H.P. hours. Hence, on a power output basis, one gallon of gasoline is equivalent to one half of one per cent. of a ton of coal. In other words, three cents' worth of slack coal costing six dollars a ton will produce as much power in a gas engine as a gallon of gasoline costing eighteen cents—six times as much.

To be commercially successful for power purposes, producer gas must not only be made automatically from the cheapest fuels, it must be as reliable as steam, and moreover, the producer should require no hand manipulation. The development of the mechanical producer for industrial furnaces is helping to solve the problem. During the past three years sufficient progress has been made to this end to justify the belief that these conditions will ultimately be met, and that some day the bituminous coal producer gas power plant will be a commercial reality, producing power in moderate-sized units as cheaply as it can now be produced in large central power stations.

Good Producer Practice

This paper has not devoted much space to the question of what constitutes good gas producer practice, as this question has recently been the subject of a comprehensive engineering paper by Victor Windate, followed by an extensive discussion which occupied an entire session of The Engineers Society of Western Pennsylvania, Pittsburgh, Pennsylvania, U.S.A. Those wishing to go into this aspect of producer gas are referred to the secretary of that society for a copy of the February, 1928, proceedings.

At a meeting of the American Iron and Steel Institute in 1923, the author gave a typical heat balance for good gas producer practice in the United States. Little improvement has been made since then, except that in some of the more recent installations the capacity is 50 per cent. greater, making it 4,224 lb. per hour, instead of 2,616 lb. The average analysis for good American practice then and now is as follows:—

CO_2	O_2	CO	C_2H_4	H_2	CH_4	N_2	Calorific Value B.Th U
4.8	0.2	25.5	0.4	12.1	3.6	53.4	154.0

Such a gas represents a cold gas efficiency of 74.61 per cent., and a hot gas efficiency of 86.03 per cent., if made from the following average American gas coal:—

Moisture	Volatiles	Fixed Carbon	Ash	Sulphur included in Ash	Total Carbon	Calorific Value B.Th.U. per lb.
3.5	32.8	56.2	7.5	1.1	74.8	13,450

The above efficiencies do not take into consideration the tar and oil vapours and the fine carbon entrained in the gas. These constituents represent from 5 per cent. to 10 per cent. of the total value of the coal, and bring up the actual efficiency of the gases leaving the producer to about 95 per cent.

THE FUTURE ENCOURAGING

The first essential for making good producer gas is good management, the second is a good gas producer. Three-fourths of the poor quality producer gas made in the United States is directly due to an uninformed management that would not tolerate such a loss in any other department. Recently some of the larger users of producer gas in the United States have employed an expert gas maker to improve their practice, with very gratifying results. In some cases these experts, by altering the gas house practice and installing a few recording devices, have saved the company ten times their salary. The time is not far distant, although it has not yet arrived, when large users of producer gas will be as solicitous about the saving of fuel in their gas house as in their boiler house. Progress in the entire field of producer gas will then be more rapid than it has been in the past, and the use of automatic producers in large and small sizes for a great variety of purposes will become universal. The art of making combustible gases is still in its infancy. Fundamental improvements are well under way. We are at the threshold of a great and important advance.

RÉSUMÉ

Le but de ce mémoire est de signaler les lignes de progrès dans le dessin de gazogènes et dans leur application que l'auteur croit les plus significatives Il discute aussi quelques obstacles aux progrès futurs et suggère des remèdes qu'il croit être efficaces à la fin.

Pendant les dernières années, quelques fabricants américains de gazogènes ont perfectionnés leur agitation mécanique et ont doublés par ce moyen le taux de gazéification L'auteur croit qu'il y a évidence abondante que pendant les années prochaines on augmentera graduellement la capacité jusqu'à 100 tonnes par jour pour le gazogène du type I.D de la grandeur de 10 pieds. Un rendement de 107 livres par pied-carré par heure a été atteint par l'auteur, sans nuire à la qualité du gaz, en accroissant la quantité et la fréquence de l'agitation par toute la couche brûlante et aussi en augmentant la capacité du soufflet.

Diverses caractéristiques du gazogène et les méthodes de manœuvrer la couche de feu sont discutées dans ce mémoire, et quelques-unes d'entre elles sont fortement favorisées. De nouveaux aspects du gazogène à alimentation par en dessous sont présentés. L'auteur voit des possibilités dans ce type et propose des méthodes par lesquelles il croit que l'on pourra faire des progrès.

GENERAL REPORT ON SECTION K

UTILISATION OF FUELS, INCLUDING ELECTRICITY, FOR INDUSTRIAL FURNACE WORK

ROGER T. SMITH

This General Report covers eighteen papers forming Section K. For convenience these papers may be divided into three groups.

GROUP A

THE QUESTION OF SOLID, LIQUID AND GASEOUS FUELS IN THEIR APPLICATION TO:—

(i) *General Industrial Furnace Work*

(a) The Hydraulic Theory of the Movements of Gases as applied to the Construction of Furnaces (Russia), by Prof. W. E. Groom-Grjimailo and Prof. M. Kirpitcheff (K16).

(b) Industrial Heating by Solid, Liquid and Gaseous Fuels (Great Britain), by Sir Robert Hadfield, Bt., and R. J. Sargant (K9).

(c) The Industrial and Domestic Uses of Coal (Japan), by K. Tsujimoto (K13).

(d) Atmospheric Pressure Burners for Natural Gas (Poland), by T Niemczynowski (K14).

(ii) *Ferrous and Non-Ferrous Furnaces*

(e) The Production and Utilisation of Gas in German Iron and Steel Works (Germany), by Dr. Bansen (K7).

(f) Low Grade Coal for Blast Furnace Coke (Japan), by Dr. Tsuruo Noda and Taizo Kuroda (K15).

(iii) *The Ceramic Industry*

(g) Economic Utilisation of Fuels in the Czechoslovakian Ceramic Industry (Czechoslovakia), by B. Helan (K3).

(iv) The Cement Industry

(*h*) The Fuel Question in the Cement Industry (Denmark), by O. V. Morch (K5).

GROUP B

The Use of Electricity for Industrial Heating

(i) General Applications

(*i*) The Thermal Efficiency of an Industrial Electric Furnace (Japan), by T. Kawasakiya (K11).

(*j*) The Use of Electricity for the Production of Heat in Industrial and Manufacturing Installations (Austria), by Dr. A. Velisek (K1).

(*k*) Industrial Electric Heating (Great Britain), by S. E. Monkhouse (K10).

(*l*) Utilisation of Electricity for Industrial Heating (Canada), by A. T. Stuart (K4).

(*m*) The Utilisation of Electricity for Industrial Heating (U.S.A.). Presented by the American Technical Committee (K18).

(ii) The Ceramic Industry

(*n*) The Application of Electricity to the Firing of Enamels on Porcelain (Japan), by Y. Matsunaga (K12).

GROUP C

The Production and Use of Gas in Relation to:—

(i) General Applications

(*o*) Industrial Gas in the United States—Growth and Trends (U.S.A.), by American Gas Association (K17).

(ii) Specialised Uses and Forms of Gas

(*p*) The Use of Producer Gas by the Ashanti Goldfields Corporation (Gold Coast) (K8).

(*q*) Wood Producer Gas for the Treatment of Silver Ores (Dutch East Indies), by A. van Hoek (K6).

(*r*) Suction Gas Producers for Motor Vehicles (France), by J. Auclair (K2).

GROUP A

The Question of Solid, Liquid and Gaseous Fuels in their Application to:—

(i) General Industrial Furnace Work

"The Hydraulic Theory of the Movements of Gases as Applied to the Construction of Furnaces" is described in three parts submitted by the Russian National Committee (K16).

The third part of the paper defines the hydraulic theory of the movement of gases. The flame movement is considered to be that of a light fluid inside a heavy fluid. Experiments are described showing the movement of hot gases round heated pipes and heated plates. The loss of heat in a free stream of hot gases is treated quantitatively.

Arising out of the hydraulic theory of the movement of hot gases, the author of the first part describes drying kilns consisting of chambers in which there is a natural circulation of hot air. Properly guided hot dry air rises from the bottom of the kiln at its sides and descends from the top of the kiln to the bottom, taking up the moisture from the things to be dried and descending by its greater weight to be heated again at the bottom of the kiln.

Adapting this natural circulation, starting from the bottom and with a separate discharge at the bottom, Part 2 describes the application of this principle to a tunnel furnace for the firing of earthenware. The system increased the output of the kiln by 30 per cent. while at the same time there was a decrease of 48 per cent. in fuel as compared with the original tunnel heating.

The "Industrial Heating by Solid, Liquid and Gaseous Fuels" is treated in a paper presented by the Technical Committee, Fuel Conference, 1928 (K9). Perhaps the most interesting section of this comprehensive paper is that dealing with solid fuel, and it will be referred to first. Mechanical stokers, owing to their high first cost, have not been largely used for intermittent furnaces, but to-day heat resisting steel can be made which can stand more than 1,000°C. without oxidation and maintain sufficient strength. Recently such heat resisting steel has been made with a definite resistance to the action of sulphur at such a temperature.

One important application of such heat resisting steel is its use in recuperators for saving furnace heat. Experience with the preheating of air by steel tube recuperators in place of the large refractory recuperators formerly used shows great improvement.

The limitation to the amount of preheating of primary air by recuperation is the excessive formation of clinker.

The authors give their own experience in connection with furnaces for steel of preheating by means of steel tube recuperators, where the temperature of the inlet gases to the recuperator range from 1,000°C. to 1,200°C. When the temperature of the preheated air was restricted to 300°C. there was no difficulty with clinker, and eighteen months' work showed no deterioration in the recuperator tubes.

Dealing with economy of fuel in furnaces the authors point out that in any industrial undertaking the capacity of each furnace must be adapted to the full range of the possible kinds of material to be heated. It is this necessity which limits the usual thermal efficiency of furnaces to something of the order of 12 per cent. Efficiency here used is the ratio of the sensible heat used in the material to be heated to the heat supplied to the furnace.

The first part of paper K9 deals with the relative advantages of solid, liquid and gaseous fuels, chiefly in reference to their adaptability factor. This adaptability factor includes site occupation by furnace and by fuel storage, fuel supply, suitability for intermittent work and labour required. In Great Britain, solid fuel is cheaper than liquid fuel (of which powdered fuel is considered as a class) or gaseous fuel, but the greater adaptability of the two latter may often outweigh their higher cost as compared with coal. Instances are given of the advantages of fuel oil for many processes in spite of the fact that since 1921 its cost for the same thermal value relative to coal is increasing.

The paper "The Industrial and Domestic Uses of Coal," presented by the Osaka Industrial Association, Japan (K13), deals with the problem of the destruction of the Japanese forests by the almost universal use of wood fuel, either as wood or as charcoal, for domestic heating. Although coal and petroleum have been known in Japan for 1,300 years, wood and charcoal have been used as fuel for 2,500 years, and the preparation of the fuel has not changed for 1,500 years.

Of 30,000,000 tons of coal raised annually in Japan 28,500,000 tons are needed for home consumption.

Nearly 3,000,000,000 cu. ft. of wood are burned annually in Japan, mostly for domestic heating, and allowing for reforestation she ought not to use more than 1,100,000,000 cu. ft.

The present development of hydro-electric power produces 6,000,000,000 kWh. annually, representing 10,000,000 tons of coal.

While the development of hydro-electric power and the import of Chinese coal would appear to meet industrial needs in Japan, unless the domestic use of wood fuel at the present rate is curtailed the deforestation of the country is assured, which, among other evils, will destroy the water power.

The proposed substitute for wood and charcoal fuel is a smokeless ligno-briquette made by the low temperature carbonisation of a mixture of native bituminous coals. Very full description is given of the apparatus and processes producing ligno-briquettes. The net cost, including overhead charges, of the ligno-briquettes is given as 57s. a ton and it is proposed to sell this at 120s. per ton compared with charcoal at 200s. per ton.

The paper entitled "Atmospheric Pressure Burners for Natural Gas" (K14), presented by the Polish Power Committee, is an analytical determination of the dimensions of the principal parts of a gas burner working at atmospheric pressure. It is designed to give the best results by altering the size of the air choke, or of the gas jet or of both together. The equations are plotted as curves with experimental results, and their comparison is satisfactory.

(*ii*) *Ferrous and Non-Ferrous Furnaces*

The "Production and Utilisation of Gas in German Iron and Steel Works" is dealt with by the Verein deutscher Eisenhuttenleute (K7). This paper is devoted to the possibilities of using blast furnace gas made in an iron and steel works producing basic pig iron in all the processes connected with the works, including generation of electricity, although the author considers that coal is best used for electric generation and for rolling mills. The works must of course, be designed to produce equilibrium between gas supply and gas consumption, including the transmission of gas to other industrial users or its sale for electricity supply generation. The whole story is summarised in flow diagram, Fig. 13.

It is not possible by any brief analysis of the paper to convey an idea of its comprehensive information to any one who has not read it. For all its conclusions the reasons for those conclusions are fully stated.

Full descriptions are given of gas purification from dust by dust catchers and then by the wet or, alternatively, by the dry process;

the economical method of gas distribution; the necessity for preheating blast furnace gas for its various uses; the advantage of enriching blast furnace gas with coke-oven gas.

For the production of power from gas the steam turbine burning the gas in a special or marine type tubular boiler is preferred to the gas engine, boiler efficiencies of from 80 per cent. to 83 per cent. being claimed in small boilers and 80 per cent. to 86 per cent. in a special boiler working at 35 atmospheres steam pressure and at 400°C. steam temperature, supplied with air preheated to 400°C. and no economisers. The waste heat boiler is condemned as comparatively uneconomical.

Describing the use of the gas in various furnaces the author advocates coke ovens heated by purified blast furnace gas at constant pressure. The whole of the coke oven gas should be used in the steel works and rolling mills.

Open hearth furnaces should be heated by a preheated mixture of blast furnace and coke oven gas, and large depths of metal bath are advocated with charges of 2 tons per sq. metre of hearth area for average size ovens, and 3 tons for tilting ovens.

The authors claim that every requirement of heat supply and of output can be met in heating furnaces by the use of blast furnace gas with or without preheating, and with or without the addition of coke oven gas.

The paper entitled "Low Grade Coal for Blast Furnace Coke," presented by the Power Association of Japan (K15), gives a complete account, with many tables and curves, showing how a fairly good coke, suitable for blast furnace work, is being made in Japan from low grade coals by careful preparation and proper heating. Many coals of different volatile content are pulverised and washed, so as to leave less than 12 per cent. ash in the coal or 18 per cent. in the coke.

(iii) *The Ceramic Industry*

In the paper "Economic Utilisation of Fuels in the Czechoslovakian Ceramic Industry," presented by the Czechoslovakian National Committee (K3), it is stated that the ceramic industry in Czechoslovakia uses 9·2 per cent. of the country's output of brown coal and 3·4 per cent. of its total output of bituminous coal.

In conjunction with the Unions of Porcelain and Glass Manufacturers, the State Institute for the economic utilisation of fuels

investigates experimentally the economics of fuel through its heat technology department. The paper is confined to the complete method of experimental investigation for circular kilns used in the brick and tile industry. Complete heat balances are given, all the losses being measured except radiation losses and heat losses in the channels. One of the deductions from these experiments is the great importance of saving heat losses at the bottom of the kiln.

(iv) *The Cement Industry*

"The Fuel Question in the Cement Industry" is discussed in a paper presented by the Danish National Committee (K5).

The author considers that the competition in ideas resulting from the controversy in the wet and dry methods of making Portland cement in rotary kilns has benefited the industry and increased the efficient use of coal, coal representing more than half the prime cost of the cement. Since powdered fuel was first used in rotary kilns in 1900, and since, for dry kilns, the high temperature exit gases were used in waste heat boilers to provide steam for all or most of the power used in cement works, the efficiency in terms of the ideal kiln has nearly doubled.

As the demand for better cement grows, more and more power will be required, especially for fine grinding. The author estimates the world's use of fuel for the annual production of 59,000,000 metric tons of cement at 24,220,000 metric tons of fuel—coal, coke, lignite, peat and oil. He considers it not impossible still to save 5,000,000 metric tons of this fuel annually.

GROUP B

The Use of Electricity for Industrial Heating

(i) *General Applications*

"The Thermal Efficiency of an Industrial Electric Furnace" is discussed by the Power Association of Japan (K11).

The author divides the efficiency of an electric furnace, in which the heat given to the furnace electrically can be accurately measured, into two parts; first, the thermo-dynamic efficiency, and, second, the relative contribution efficiency. The author gives definitions of these factors and says the product of these two quantities is the thermal efficiency of a furnace.

It would seem that the efficiency used in the paper by Sir Robert Hadfield and R. J. Sarjant (K9) and quoted by the authors of this paper from a work by M. D. K. Thomson, namely, the ratio of heat actually used to heat the reacting substances to the required temperature plus the heat absorbed by the reaction to the total heat supplied will remain in use until it can be bettered.

In the paper "The Use of Electricity for the Production of Heat in Industrial and Manufacturing Installations," presented by the Austrian National Committee (K1), it is stated that in Austria there has been a steady growth in the use of water-power generated electricity for heating water, steam raising, mould drying, rivet heating, welding, smelting and reverberatory furnaces. Other uses are being explored. The effect of a night load for heating purposes on electric generating stations has greatly improved the twenty-four hour load curve, and the paper tabulates the additional loads on power stations due to the use of electricity for heating. Raising steam by electricity is said to be economical when a kWh. does not cost more than from $\frac{1}{3}$ to $\frac{1}{4}$ of the cost of a kilogram of coal.

"Industrial Electric Heating" is discussed in a paper presented by the British Electrical Development Association (K10).

Many of the uses in Great Britain, where electricity is mostly generated from coal, of electric heating and industrial electric furnaces are given. An analysis of some two and a half billion B.Th.U. used in engineering works, brass foundries, ship yards, paint works, soap works, potteries and bakeries shows that the percentage of the total heat units used for power to the energy used for heating varies from $\frac{1}{2}$ of 1 per cent. in potteries to $6\frac{1}{2}$ per cent. in engineering works. The general experience is that although the cost of the actual heating is greater than with fuel, the results are so satisfactory that its use in Great Britain is extending. This applies especially to the heat treatment and tempering processes.

In a paper, No. K4, "The Utilisation of Electricity for Industrial Heating," presented by the Canadian National Committee, the author develops the view that since the fundamental constituents of fuel are hydrogen, oxygen and carbon, and that combustion in a hydrocarbon fuel is hampered by the 80 per cent. of nitrogen in the air, pure oxygen for the enrichment of air will be made in the future by the electrolysis of water. Water rather than air is chosen, because of the liberation of the oxygen and hydrogen in complete separation, and the value of the latter as fuel.

The author shows the advantage to electric supply in filling up the seasonal valleys of the electricity load curve by such an electrolytic load, and, provided the oxygen and hydrogen are cheap enough, *i.e.*, if the electricity is cheap enough, he predicts the use of fluid fuels (which include gas). The author considers that cheap oxygen and hydrogen having many industrial uses, can be obtained for 5 cents, or one halfpenny per 1,000 cu. ft. by the use of peak hydro-electric current.

The "Utilisation of Electricity for Industrial Heating" is discussed by the American Committee (K18).

It is estimated that in the U.S.A. some 2,000,000 kW. of electricity are being used for industrial heating, representing a little more than 10 per cent. of the electric motor load.

Electric heating at high temperatures is used successfully for ferrous and non-ferrous metal smelting with the advantage that the furnace gases can be made oxidising, reducing or neutral at will. The electric heating of ovens, mostly to temperatures not exceeding 1,000°F., includes vitreous enamelling and japanning, baking, drying and very many other uses.

A survey made in 1926 suggests that there is an industrial heating load in the U.S.A., inclusive of commercial electric cooking and baking, which could employ 47,000,000 kW. The paper is well illustrated by photographs of electric furnaces and ovens.

(ii) *The Ceramic Industry*

"The Application of Electricity to the Firing of Enamels on Porcelain" is presented by the Japanese National Committee (K12).

The cost of electricity for the electric heated kiln, when the kWh. used at night costs 0·4d., is half the cost of fuel for the wood-fired kiln. The average total cost—inclusive of the replacement of the kiln whether for electric or wood fuel every year—of each firing with all capital charges, not only on the kilns but on the land and buildings occupied, results in the wood-fired product costing double the electric-fired product.

The chief technical advantages in the electrically heated kiln are the time saved in heating up and cooling down, the complete absence of moisture in the kiln, and cleanliness—all of which show themselves in an improved product. The effect of the night load where electric kilns are used in improving the load factor of a large electric substation are shown diagrammatically.

GROUP C

The Production and Use of Gas in Relation to:—

(i) General Applications

The paper "Industrial Gas in the United States—Growth and Trend," presented by the American Gas Association (K17), is an outstanding contribution and contains a most valuable survey of the industrial use of gas in the United States. The publication of the illustrated appendix to this paper has been made possible by special financial arrangements with the American Gas Association. In this paper it is shown that the use of industrial gas has increased by 93 per cent. in eight years. The development of modern heat treating practice is shown by photographs and data.

(ii) Specialised Uses and Forms of Gas

In the paper "The Use of Producer Gas by the Ashanti Goldfields Corporation," presented by the Ashanti Goldfields Corporation, Gold Coast (K8), the author describes the economies in fuel cost in this undertaking in the production of electric power by producer gas made from wood refuse in a pressure type producer replacing suction type producer gas made from anthracite.

It is stated in the paper "Wood Producer Gas for the Treatment of Silver Ores," presented by the Dutch East Indian National Committee (K6), that most of the silver in Sumatra is present in the ore combined with manganese, and the ore must be smelted in a reducing atmosphere to make the product soluble in cyanide. Both heating and reducing are carried out by producer gas made from wood. The producer is described and the dried wood fuel, mixed with about 10 per cent. of charcoal, yields a gas containing about 55 per cent. of the calorific value of fuel.

In the paper "Suction Gas Producers for Motor Vehicles," presented by the French National Committee (K2), it is stated that progress in gas generation has led to great simplification by eliminating steam injection and air preheating. Producers for burning charcoal with downwards combustion and fabric gas filtration are being used, and careful design reduces attention to a minimum, but owing to the weight of the apparatus, transport capacity, as compared with the petrol engine, is reduced. The difficulties of combustion in the producer under maximum, minimum and zero output of the engine are discussed together with the physical nature and condition of the combustible, and the qualities of a standard synthetic fuel. The price of combustible must be 40 per cent. of that of petrol to make competition possible.

DISCUSSION

FRIDAY, SEPTEMBER 28 (AFTERNOON)

Section K

UTILISATION OF FUELS, INCLUDING ELECTRICITY, FOR INDUSTRIAL FURNACE WORK

Chairman: MR. GEORGE A. ORROK (U.S.A.)

MR. ROGER T. SMITH presented the General Report.

MR. N. RYLAND DAVIS (Great Britain), speaking with regard to induction furnaces, said that the phrase "high-frequency" became so closely associated with the coreless induction furnace in the early days that people were led to believe that only the ring type of furnace could operated at 50 cycles, and that the coreless furnace must operate at much higher frequencies. That was not true. It was now well known that the frequency required with the coreless type of furnace depended only on the size of the furnace and resistivity of the material. The lower the resistivity the lower was the frequency which could be employed. A furnace which melted steel at 500 cycles would melt a metal of one-tenth the resistivity on 50 cycles, and experience had shown that a 600 lb. brass furnace would operate as efficiently at 50 cycles as at any higher frequency. The elimination of the motor generator set resulted in a very considerable economy, and such furnaces would melt brass or copper with a power consumption of 300-450 kWh. per ton and 500 kWh. per ton in the case of copper nickel. Thus, this type of furnace combined the convenience and flexibility of the "so-called" high-frequency furnace without the disadvantages of a motor generator set.

SIR ROBERT HADFIELD (Great Britain) said that it was not so long ago that he was president of the Society of British Gas Industries, and he devoted a portion of his Presidential Address to the study of fuel and gas technics. At that time the Fuel Research Board had only just been established and there was not very much information available with regard to these particular subjects. That Presidential Address, which consisted of some 80 or 90 pages containing important data, was distributed to the extent of 2,000 copies, and from what his many friends had been kind enough to tell him, he believed it had helped a large number of the younger men, because it contained the results of a great deal of experience in his own works during the war, when enormous amounts of gas and electricity were consumed by his Company's works. Referring to the paper by himself and Mr. Sarjant, Sir Robert said that in his works they had been actively engaged in trying to meet the wants of

engineers by giving them heat-resisting alloys which would show very high resistance to heat effects. One remarkable instance of what had been achieved was in the case of some rotor parts for the Government in relation to superchargers for certain aeroplanes. These parts were about 10 in. in diameter, did not weigh more than 74 lb., and were required to work in the hot gases from the engines at a temperature of about 850°C. to 900°C., and in some cases as high as 950°C. That was a very severe test, because in ordinary steel most of the tenacity was lost beyond 600 or 700°C. Moreover, these particular parts were revolving at 25,000 R.P.M., so that considerable strain was imposed upon them. A material was provided which stood up to these exacting conditions, and it was an instance of the advisability of the engineer in the future having at his command heat-resisting materials which could be safely relied upon. A great deal of study was now being given to creep stress, which was important at high temperatures owing to the difference in the stresses which occurred; and before long he believed it would be possible to supply even more reliable materials to withstand high temperatures and pressures. Some of the heat-resisting materials turned out by his firm has been used upon the ships of the Canadian Pacific Railway Co. for mechanical stokers. Two of these steamers recently made the double journey across the Atlantic without any trouble, and, as a matter of fact, there had been no trouble throughout a large number of such journeys. Thus, engineers could be assured that better heat-resisting materials were gradually coming within their reach. Whilst these results concerned the productions of his own firm, yet he felt that he could not do better than refer to actual instances of practical work coming within his own experience. The recuperators mentioned in the paper were employed in a very important Government works in this country not far from London, and without these particular steel parts it had been found impossible to get the desired duty.

Mr. T. Settli (Great Britain) said that the baking of bread and confectionery by electricity was one of the applications of industrial electric heating where the advantages of the electric method were most obvious. The electric baking oven, even in larger sizes, could be considered a transportable piece of apparatus which could be assembled and dismantled easily. It took less space than many fuel-fired ovens, and he knew of a case where one double-deck half-sack oven occupying a space of 11 ft. by 7 ft., had replaced two side flue ovens 22 ft. by 12 ft. which were not capable of producing the same output over the same period. This saving of space was of great importance, particularly to smaller establishments. In addition, there was no space required as in the case of coal- or coke-fired ovens for the storing of fuel and ashes; and the space previously required for such fuel would be available for other purposes. Cleanliness and the very satisfactory influence on the atmosphere in the bakeries, and hence on the health of the workpeople, were beyond dispute, and he could quote a case of one particular bakery where not a single man had been away ill since the installation of electric ovens

twelve months ago. Previously, one or more were constantly away owing to illness, attributed in some cases to sulphur fumes and dust. The men were working under better conditions, and it had been found that when called upon to give output above the normal it was now cheerfully done, when previously the instructions were received sullenly. By the introduction of electric baking ovens most of the objections to underground baking would seem to disappear. At present, in this country underground baking was not encouraged, but in view of the enormous improvement in the sanitary conditions some of the objections were likely to be overcome.

The adaptability of the electric oven was unique. There was no type of oven at present available where such complete control could be given as by the electric oven. The nearest approach was the steam pipe oven, but there again there was not the complete and easy control of top and bottom heat. This was of great importance; especially to a baker in a small way of business who might have to depend on one oven only, through lack of space. He knew of cases where the actual expenditure for electricity without taking into consideration other factors, had been lower than the cost of fuel, and at the rate of ½d per unit for current, electric baking was competitive with all other methods. This applied equally to small and large installations Even ¾d. per unit, and in cases where a mixed trade of bread and confectionery was being done, even a higher rate per unit, were economic propositions. As was the case with other industrial problems, the bakers were likely to compare in the first instance, the cost of electric current with the cost of fuel. The only proper way, of course, was to compare the all-in cost of electric baking with the all-in cost of other types of ovens. There were many bakers who would not disclose their actual cost, but they were satisfied that they were saving against their previous methods. If the cost of fuel of any kind did not exceed 1 per cent. of the turnover, the results were usually satisfactory to the baker, and with electric heating this result was easily obtained. The saving against other methods consisted primarily in saving of space, saving in labour, better utilisation of heat owing to the construction of electric ovens, and a certain saving in dough. This saving might not be exclusively limited to electric ovens, but it was achieved with all electric ovens of metal construction, which was not necessarily so with fuel-fired ovens.

In most cases, especially in larger establishments in this country, baking was carried out during the night, possibly up to mid-day or early afternoon. The peak was usually avoided, and, therefore, electric baking ought to be a valuable addition to the output of electric supply undertakings, as it would assist them to fill up the valley between peaks. It ought, therefore, to be possible for supply undertakings to quote special rates for this kind of load, and he was glad to say that in some instances in this country this was being done. American supply undertakings charged rates for current according to the consumption. The higher the consumption the lower the figure per unit. This encouraged bakers to increase their

output. During the last year a very large bakery installed three baking ovens with a total maximum load of 170 kW. This installation was working to the entire satisfaction of the users and of the supply undertaking. Since it had been started not a single loaf of bread had been spoiled, and the workpeople would not, for anything, return to the old method.

MR. W. F. GIFFARD (Great Britain) remarked that the statement in the general report that the general experience was that, although the cost of electric heating was greater than that of fuel, the results were so satisfactory that its use in Great Britain was extending, required a little explanation. In the case of any process of electric heating, it was often the case that this type of furnace was installed because it was cheaper. In other cases the cost of installation was higher but the quality of the product was better, whilst in other cases both advantages were obtained. For steel smelting it was generally recognised that the arc furnace was cheaper than the crucible furnace and more expensive than the large open hearth furnace. In the case of small open hearth furnaces or converters, the cost varied with local conditions, the relative prices of pig-iron and scrap and the relative price of electric power and fuel. In the case of the cored electric furnace for melting brass, such furnaces were being installed because the cost of the product was cheaper. There were over 600 furnaces of one type in operation all over the world, making something over one million tons of brass annually, and the power consumed was of the order of 250 million kWh. per annum. All this development had taken place in a period of eight or ten years, and not only was the cost of the final product cheaper, but it was also claimed to be better. It was difficult to get definite costs of crucible furnaces because of the varying conditions in different works, but the average cost of melting extrusion billets of 60/40 brass in Birmingham was about £1 16 0 per ton, whilst the electric furnace and power at 0·6d. per unit the cost was £1 3 6. With other savings, however, such as the saving in zinc loss, which varied at different works, there was an estimated saving in favour of the electric furnace of £1 per ton, which included depreciation and other charges.

In the paper by the British Electric Development Association, it was stated as regards the high-frequency furnace that the largest furnace of this type installed was equipped with a 200 kW. motor generator, but that probably furnaces capable of dealing with 100 tons would be available before long. That prophecy had been very rapidly fulfilled, because a machine had just been installed in England of 650 kW. capacity, and it would be used for working a 1-ton furnace and was expected to be in operation before the end of the year. The first commercial furnace of this type was installed a little less than a year ago, and in England and France there would be fifteen furnaces in operation before the end of 1928 with a total capacity of 2,500 kW., using 7 million units per annum. Where the limit was likely to be it was difficult to say. These furnaces were being put in competition with crucible furnaces for the reason that

the cost was considerably lower and that they made a better quality steel. Figures recently published show that with high-speed steel of exactly the same composition made by the same firm in the two types of furnace, the steel made in the electric furnace removed 11·5 lb. more of material as compared with 6·1 lb. in the case of the crucible furnace. This was a 14 per cent. tungsten steel. In the higher grades of steel the material produced by the high-frequency furnace removed 21 lb. as against 16 lb., and 42·8 lb. as against 36·1 lb. Thus there was both cheaper quality and lower price in favour of the electric furnace. It would really be interesting to get some figures of tonnage in competition with the open hearth furnace. The fact was that a 2-ton furnace was no larger than a small table, but it was capable of producing as much steel as a 20-ton open hearth furnace, and when this difference in size was considered (a 3-ton electric furnace would have the same capacity as a 30-ton open hearth furnace) and also the great convenience of being able to make small quantities of steel as and when required instead of only large quantities, there should be a very big development in the future.

The reason why high-frequency furnaces were being employed was because the number of condensers varied inversely with the frequency, so that a 50-cycle furnace would require fifty times the number of condensers as compared with a 2,500-cycle furnace. Resistance furnaces were sometimes put in because the actual cost of heat treatment by them was lower and in other cases because the quality of the product was better and, in consequence, the number of rejections was less. A furnace for heat-treating aluminium alloys would do the work for half the cost of a coal-fired furnace.

Mr. C. W. Spiers (Great Britain) said he thought a feature which had not been dealt with very fully in the papers was the question of suitable means of turning electrical energy into heat. For low temperature—by low temperature he meant under 1,000°C.—nichrome wire had proved very unsatisfactory. For higher temperatures—up to, say, a maximum of 1,500°C.—progress had been delayed by lack of a suitable resistor. (High temperature could, of course, be obtained in the melting of metal by inducing the current in the metal to be melted, but this method had obviously only a limited field). Various papers clearly indicated the great saving to be obtained by burning delicate articles like china and pottery in the electric furnace. One paper (K12) dealt entirely with this subject; but it was limited to low-temperature firing, and this represented probably less than 10 per cent. of the firing processes in the manufacture of pottery. It was of interest to note that even in a periodic kiln which was very inefficient, the author claimed a higher efficiency for the electric kiln than a direct fuel-fired kiln. In K10, pages 1053 to 1055, were notes on the same process with an electric tunnel kiln. This being a continuous kiln, would be of higher efficiency than the Japanese periodic kiln. It was satisfactory to note that a start had been made in the English potteries with electric firing.

In paper K10, page 1038, there was a table showing the amount of

fuel measured in B.Th.U. used in the pottery industry. He thought it was safe to say that at least half of the kilning processes in use in this country at the present time could be replaced economically by the use of electricity. For biscuit and glost firing, which required high temperature and were responsible for the chief use of fuel in the pottery industry, coal-fired kilns were being replaced in the pottery industry. They were being replaced in a Swedish pottery by the use of electrical kilns employing a new type of resistor, which was gradually being perfected in detail. It had been found that resistors measuring 7 in. by 2 in. by 1 in., mounted as a wall or roof of a tunnel kiln, would operate continuously for three months, dissipating to 40 kW. at a temperature of 1,300°C. This information should be of value to those interested in the design of high-temperature electric furnaces. It was a remarkable fact that the Swedish pottery using these kilns had proved that they produced more and better ware per ton of coal burnt in their boilers than they previously produced per ton of coal burnt in the fire holes of their old kilns, in addition to a lower labour cost and many other advantages. There were many reasons for this saving, but it was chiefly due to the fact that a round periodic coal-fired kiln (and this was the type used in most cases all over the world), had an extremely low heat efficiency; while an electric kiln consisting of a tunnel, very well heat insulated, and with two tracks inside carrying ware in opposite directions, was probably the kiln with the highest possible heat efficiency. The most important feature of a high-temperature electric furnace was that the point of highest temperature was the resistor, often only a few degrees higher than the temperature of the ware fired Only experience with furnaces of all types would show the enormous saving in maintenance for this reason. The temperature of the fire holes in a fuel-fired kiln were often several hundred degree above the temperature of the ware.

MR. A. GLYNNE LOBLEY said it was frequently assumed, and the report and some of the papers seemed to encourage the assumption, that electric heating cost more than direct heating by fuel, except in rare instances. While agreeing very strongly with the view that the energy cost, taken by itself, was no criterion, he felt that it was essential to dispel the idea that electrical heating was, of necessity, expensive. In many processes it had been found that a direct saving had been effected. An electric furnace could be very thoroughly insulated, and there were no flue losses. This advantage was especially felt in processes where the charge had not only to be heated, but kept hot for a considerable time. Once the charge was heated the electrical energy required to maintain the temperature was comparatively small, whereas with the direct-fired furnace the fuel consumption was often little less than during the heating-up period. It should not be forgotten that whereas the efficiency of the fuel furnace almost invariably deteriorated with use, that of the electric furnace did not. In one case in his own experience, a small electric furnace replaced a gas furnace for annealing brass stampings. The result exceeded the user's expectations. The cost of the power

was reduced by half, the output increased by 25 per cent., oxidation reduced—so saving pickling—and the uniformity of annealing resulted in the entire elimination of rejects in pressing. The advantages were both direct and indirect. In another case a furnace was installed to heat thick steel plates for straightening and bending. The advantages looked for, and obtained, were those of being able to place the furnace in the best position from the point of view of other machinery, of being able to arrange a convenient method of charging and discharging and having a furnace which required no attention. The result had been that the direct labour costs had been reduced by an amount roughly equal to the total cost of the electrical energy consumed.

In the case of aluminium, where great accuracy of control of temperature was required, electric heating was the only way of obtaining reliable results. But even had this accuracy not been required, electric heating would still score as it was a long period process. While it was often found that the direct costs were lower with electricity, the advantages which reduced indirect costs were, undoubtedly, more important. The improvement of quality and elimination of rejects, due to the even heating and exact control, the convenience of operation and adaptability to special requirements, were but a few of the advantages which often had a very great bearing on the ultimate cost of production.

Mr. Glynne Lobley then made a few remarks about paper K11—"Thermal Efficiency of an Industrial Electric Furnace." The author, in trying to reduce the question to a general formula was, according to the speaker, attempting the impossible; and moreover, the use of such a formula as the author had arrived at, would give most misleading results if used in specifications, etc. The older definitions, such as Thomson's, might not be entirely satisfactory, but taken in conjunction with other known conditions of operation, were far more useful than the more complicated formula arrived at in this paper. One case which showed up the weakness of the older definition was that of the counter-current furnace, where heat was exchanged between the out-going charge and the in-going charge. Calculated in the older way, efficiencies over 100 per cent. might be obtained; and whilst these appeared absurd, they were, nevertheless, a useful aid in comparison. Calculated by the new formula, we actually obtained a lower efficiency with the counter-current furnace than with the ordinary furnace—an obviously absurd result. And the more perfect the heat exchange, that is, the less heat left in the out-going charge, the lower the thermodynamical efficiency. Practically speaking, the efficiency of an industrial furnace was a cost question and could be judged with the aid of the Thompson definition of efficiency, taking into account many other factors such as depreciation, etc.

Col. W. A. Vignoles (Great Britain) said the importance of industrial heating was emphasised in paper K10, in which was a table showing that in most works the power used, expressed in heat units, was only a small percentage of the total heat required in the

works. In the case of a shipyard, only 2·9 per cent. was used as power, the remainder being used in various works' processes. Therefore, the question of economy in industrial heating processes was one of the greatest importance. Those who had not studied the question of electric heating sometimes ridiculed it because they could not see how electricity that had been generated from heat, during which process there were considerable losses, could be converted back again into heat. The difficulty of such people seemed to be to appreciate why electrical heating was, under certain conditions, a practical process. In the first place, the efficiency of the electrical heating apparatus was usually very considerably higher than that used in any other method of heating, and in one case he had been told that where a pottery adopted electric heating, the coal fired into the boilers used for generating the electricity was less than when coal was used directly. Further, it had to be considered that in many cases the grade of fuel used for the generation of electricity was lower than that used for direct coal firing, so that the cost of the fuel per ton might be considerably less. Further, there would be a great saving in labour when using electricity, and a further saving in the amount of rejected material owing to the better regulation of the process, and still further, an improvement in the quality of the product. All these things put together helped to make the electrical process a practical one and economically satisfactory. There was also the point in favour of electric heating, which was not stressed so often as it should be, and that was that the electric process brought to the small works plant which could not be used if coal or other means was employed. A small electric furnace could be easily regulated and made to produce a product with which no coal-fired furnace of a similar size could compete. For example, arc furnaces were made in small sizes and enabled the small works to make steel castings at a very much lower cost than is possible in any other way. He had just received a letter from Mr. H. W. Clothier, of Messrs. Reyrolle, of Newcastle-on-Tyne, relating to some electric furnaces installed for the heating of plates and other purposes. In this letter it was stated that a comparison of cost of fuel is no criterion of the economic value of electric heating apparatus; electricity could be applied exactly where it was required, a great saving was made in the cost of handling coal and ashes and in the storage of the fuel, whilst, in addition, the process was speeded up. A particular case in Messrs. Reyrolle's works was the straightening of 1¼ in. thick plates weighing 350 lb. It was stated that if these were straightened in the steel works before delivery, the extra cost would be 50/- per ton. Done in the firm's own works with the previously used coke furnaces, the extra cost was 14/9 per ton, and with electric furnaces it was 13/9 per ton; the capital charges, however, on the electrical plant were very much lower, although the actual capital cost of the plants was about the same as the output from it was twice as great. There was also more even heating and freedom from scale, whilst by automatic control, Messrs. Reyrolle found they could keep the temperature of the

furnace within 1 per cent. A further advantage was that the furnace could be switched on in the early morning by the night watchman ready for the day's work, or it could be controlled by means of a time switch. These same furnaces were arranged with an automatic cut-off, so that when the furnace was open the supply of electricity was cut off. The furnace at Messrs. Reynolds's works operated at 950°C., and the elements had been in use for twelve months without renewal. Electricity was also used in the same works for enamelling purposes at a temperature of 300°F. Greater speed was obtained, because four bakes per day were possible as compared with one in the type of furnace used previously, which was steam heated. An improvement in the finish had been noticed, owing to the absence of dust, which was taken care of by filtration. If there were any American delegates present he would be pleased to hear what was being done on the other side, because he understood that one of the great advantages of using electric ovens in enamelling parts of motor cars was a very much improved product, owing to the possibility of excluding all dust during the process.

DR. KAWASAKIYA (Japan) referring to the flow of heat through furnace walls, said it was entirely impossible, within the present scope of science, to know the exact rates of heat-flows through furnace walls when in a transient state. Therefore, an empirical formula should be adopted for practical use, and he had derived an empirical formula from certain approximations of analytical expressions which included infinite series of slow convergency. This approximation was based on the assumption of variable time constants, which were expressed by the products of the thermal resistance of the walls and the apparent thermal capacity of the furnace, with or without charge. The transient temperature rise calculated by the formula was generally in accordance with the data obtained by the experiments of an electric furnace. Turning to the thermal properties of refractory materials, he called attention to the following facts. According to the results of researches made by Dr. Tadokora, of the Imperial Japanese Steel Works, the specific thermal capacity of an ordinary shamotte brick reached a maximum at about 500°C., where it changed the sign of its temperature coefficient. On the other hand, diatomaceous earth bricks showed a very slight change in their specific thermal capacity, for different temperatures of moderate range. These facts might explain the premature appearance of excessive surface loss over the brickwork storage which Sir Robert Hadfield had pointed out in his paper, provided the brickwork was of the character mentioned. Finally, as concerns the critical rate of heating, the following general features were pointed out. It would be easily understood that there existed one critical rate of heating at which a maximum thermal efficiency was obtained, if we considered the increase of losses due to incomplete combustion of fuel and heat carried away with waste gas in a fuel-burning furnace. As for electric furnaces, the circumstances were somewhat different, and the thermal efficiency was increased with

the rate of heating, although its increment diminished against the increase of the latter.

MR. MORCH (Denmark) referring to his paper (K5) on the utilisation of fuel in the Portland cement industry, said it was fitting that a paper on this subject should be presented on behalf of the Danish Committee, inasmuch as the cement industry was one of the largest consumers of fuel in Denmark, and at present all the fuel was imported, there being no coal or oil in the country. The importance of the fuel problem to the Danish cement industry would be appreciated when it was stated that half of the Danish cement was exported and had to compete with that of other countries, where fuel resources were plentiful. He had come to this country, which was the largest supplier of fuel to Denmark, to learn how to use less of the fuel which Denmark bought here. He believed the policy of this country was essentially liberal. The statistics available with regard to fuel in the cement industry in Denmark were not very complete, and consequently figures he had given in his paper must not be regarded as being absolutely correct, but he hoped that would give an indication as to the position of the Portland cement industry to-day. In writing the paper it had been his intention also to give an idea of what might be done perhaps in other industries. He had attempted to arrive at a figure indicating the efficiency of fuel utilisation in the cement industry to-day, assuming the maximum possible efficiency to be 100, and he believed this figure to be as valuable as figures of total fuel consumption. With regard to quality of fuel, he said the cement industry, as well as all others, was extremely interested in securing a thorough classification of fuel. Classification would effect great savings in the industries using the fuel.

MR. R. J. SARJANT (Great Britain) said that a paper of outstanding interest in furnace work was K17, which gave a very comprehensive account of the state of progress, and the marked degree of progress, in the use of industrial gas in the United States. It was also to be noted from the statistics supplied by the largest gas undertakings in Great Britain that the proportion of industrial gas used for industrial heating, expressed as a proportion of the total gas used for all purposes, was, as near as possible, 10 per cent. The further outstanding point was that the the increase in the rate of use each year was only of the order of 1 per cent. The cost of producer gas in iron and steel works, of which he could speak with some familiarity, was of the order of 1·3d. to 2d. per therm. In a city of the industrial north, where coke oven gas was readily available, the cost per therm supplied to the furnace—and he wished to lay stress on that point—was within measurable distance of the requirements of iron and steel works, taking into account that very important factor, adaptability, about which so much had been heard in the discussion in regard to the electric furnace. There was still a gap to be bridged, however, and it could safely be said that we had not yet seen the death of solid fuel. The competition of solid fuel, however, would depend upon the progress made in accommodating the use of solid

fuel to the furnace, and in particular, on the progress made in the development of the mechanical stoker for small units. The possible combination of air heating—both primary and secondary air—was also within measurable distance of adoption with the materials of which Sir Robert Hadfield had spoke. As regards pulverised fuel, the fact encountered was that in many industrial establishments the furnace was a small unit which must be placed in a particular part of the shop, and as one of the minor aspects of the general shop problem it had to be relegated to a secondary position in regard to the whole scheme. From this point of view he did not feel able at the moment to recommend pulverised fuel to his directors as suitable for small units in iron and steel works. The point raised by the Japanese speaker was of great importance, because in his own case also an attempt had been made to study the flow of heat through the various structures, and also in the material of the charge under conditions of intermittent working. It was a problem of tracking down heat units, and it was a very dominant problem in furnace matters. It was also a most difficult question, and he urged that work should be done upon it and encouraged.

Then there was the controversial point of furnace efficiency. He did not think it mattered what we called furnace efficiency as long as it was defined at the time it was being dealt with, and everybody knew what was meant. The normal definition was a very useful one within a limited sphere, but it must be realised that there was another factor in industrial furnace operation, especially in Great Britain, which had very serious significance, *viz.*, the amount of heat required to raise the furnace to working temperature, and that was a problem of equal importance with furnace efficiency.

As regards electric heating, this had been considered to displace oil in one of the Hadfield shops for the heating of springs. The actual cost of the tempering and hardening of springs with the oil furnace was 1/8 and 7/6 per ton respectively, whereas with electric heating under continuous load the best costs were 8/- per ton for the tempering and 16/- per ton for hardening, and nothing had been found in ancillary savings to bridge that gap between the costs.

Mr. L. H. Sensicle (Great Britain) referred to the suggested use of off-peak load electricity put forward by Mr. A. T. Stuart in paper K4. In his interesting suggestion to fill up the seasonal valleys of the electricity load curve by electrolysing water, he had seemed to lay the emphasis in the wrong direction by suggesting an energy conversation. The amount of energy required in electrolysing water was exactly equal to that obtained if the resulting hydrogen and oxygen were recombined. At first sight it might appear, so to speak, possible to store electricity in gasholders by storing the resulting hydrogen and oxygen. But by no known process was it possible to recover that energy as electricity to a greater extent than 30 per cent. of its original value. The attractiveness of the suggestion lay in its chemical aspects. The hydrogen could be used in a number of processes such as the synthesis of ammonia, the hydrogenation of

oils and naphthalene and even coal itself. Such processes demanded cheap hydrogen for their success, and it was here suggested that the hydrogen in this case could be obtained for 5 cents or one halfpenny, per 1,000 cu. ft. As regards the oxygen it did not seem that much value could be attached to its use for enriching air for use possibly in boilers, since the efficiencies obtainable in boiler practice were already exceptionally good. The chief losses in electricity generation occurred in the prime mover. The oxygen might, however, if suitably situated, prove of value in metallurgical processes, it having been shown that great economies could, for example, be effected in blast furnace operation if an oxygen enriched blast were employed.

Mr. George Helps (Great Britain) said that Sir Robert Hadfield had reminded them of the time, some few years ago, when he (Sir Robert) was President of the Society of British Gas Industries. At that time Sir Robert was particularly interested in the use of town or high-grade gas for furnace work. In his Presidential Address to the members of the British Gas Industries Society, Sir Robert had referred to the work then being done at Nuneaton. Sir Robert Hadfield no doubt would be interested to learn that since that time many advances had been made, and at the present time the quality of gas distributed from Nuneaton Gas Works was about 200 B.Th.U. Personally, he had not much experience of the firing of steel furnaces with gas of either 500 or 200 B.Th.U., but from general principles he took it that if the flame temperature of a 200 B.Th.U. gas was almost that of a 500 B.Th.U. gas there could be no question of the practicability of so applying it. At the present time gas was being produced in Nuneaton from local coal, costing less than £1 per ton (but he would take it at £1), and it was possible to supply such a gas at 1d. per therm, or thereabouts profitably, including interest and depreciation charges. He had felt some little diffidence in speaking this afternoon until he heard Mr. Sarjant. That speaker had referred to the use of producer gas (about 130 B.Th.U.) in iron and steel works, and had mentioned the cost of such gas as 1·30 pence to 2·0 pence per therm. Mr. Sarjant appeared to be a man after his own heart. He only wished Sir Robert Hadfield had a steel works near Nuneaton so that he could supply 200 gas at about the figure he had named. He (Mr. Helps) had been making gas in this country and abroad for over forty years. Since 1916 he had been making gas of all qualities from 600 to 160, and he had distributed gas to 6,000 consumers through 36 miles of mains in all qualities down to about 180 B.Th.U. The results of the latter had been fully equal to those obtained with, say, 500 gas. His practical experience enabled him to say that the lower quality (within very wide limits) gives the greater facility in use. Probably the statement regarding flame temperature would not be accepted from him, but Dr. Davidson, who had tested it out, would say that the difference in the flame temperature of, say, a 500 and a 200 B.Th.U. gas was a mere bagatelle. This, he was sure, would be particularly interesting to Sir Robert Hadfield, because during the war there were big users of gas in Sheffield who complained that if the quality dropped from

about 550 to 549 they could not obtain the necessary heat from it. This statement was made by great firms in Sheffield.

In regard to flame temperature, he believed that it depended absolutely on the rapidity of combustion. There were also some inherent advantages concerned with 200 B.Th.U. gas (or a low quality gas, not necessarily of 200 B.Th.U.) that permitted the development of more B.Th.U. on a given area of burner head or in a given space, than was obtainable with a richer gas. That fact had puzzled Dr. Davidson somewhat, and it had troubled himself also. Perhaps when he spoke thus of 200 B.Th.U. gas, a great deal of what he said would not be believed, and this would not surprise him. For how many of those present had used such a gas? We only really knew what our own experience had taught us. If he had not used 200 B.Th.U. gas himself, and if people had spoken to him about its advantages as he was speaking to them, he would not be a believer either. For that (their disbelief) he did not blame them, but when they would not take the trouble to enquire into the truth concerning his statements (which, if true, were of vast importance), that was another matter—that attitude he could not deprecate too strongly.

Something more than talk was demanded from a Conference of this kind. This country was too full of talkers. (He did not know about other countries because he had not been abroad lately, but he hoped to see the great scheme of gas distribution in the Ruhr country before long.) This country required men of action, men who would do something beside talk. Talk that did not lead to work was absolutely futile.

In concluding his remarks he would like to refer to the sparsity of press notices. The most important part of a paper was the discussion on it. He had sat in the body of the hall that day intensely interested, but it was only a sentence now and again that could be heard. One of the great privileges of a conference such as this surely was that it enabled those present to come into personal touch with those who had similar interests and sympathies—men who were working in a similar direction—with whom they could shake hands and discuss their problems and achievements. Therefore, he was wondering whether anything could be done to enable them to have printed copies of the various speeches, say, the day after the discussion? If that could be done he was certain the Conference would result in greater benefits to all concerned.

THE CHAIRMAN reminded Mr. Helps that a report of the discussions would be published in the Transactions after the Conference.

SIR ALBERT KITSON (Gold Coast) said that the use of producer gas was of great importance in mining districts in many parts of the world where timber was available and where the cost of ordinary fuel, especially coal, was prohibitive. On this question there were two instructive papers, one from the Dutch East Indies and the other from the West Coast of Africa. Both of these showed what engineers had been able to do with the opportunities they had found available. Only those who knew how rapidly forests were

being depleted by the burning of timber knew how injurious the effect was upon the prospects of mining in remote districts. In certain portions of the Gold Coast there were areas in which thousands of acres had not a matured tree now because all the timber had been felled and much of it wasted. The reason was that only such parts of the trunk were used as could be economically cut and transported to the mines for use in boilers, but with the use of producer gas there was the opportunity of using practically all portions of the trees, and so enlarging the stock of available fuel. From this point of view it was greatly to the credit of the engineers of the Ashanti Gold Corporation that they had been able to get power at such a low rate. It was also to the credit of our Dutch friends in the East Indies that they had done the same thing under more adverse climatic conditions, which necessitated the drying of the wood before use and thus raised the cost. This applied to the Gold Coast as well, although perhaps not to the same degree as in the East Indies. He, therefore, wished to emphasise the desirability of extending the use of producer gas and so to reduce the great expense of transporting the timber long distances, as is usually done now The present system frequently involved the transport of heavy machinery long distances at great expense and with serious delays

DR C M WALTER (Great Britain) said that as one interested in the application of town's gas for a number of years, he would like to say something on this question as compared with the use of electricity for that purpose Incidentally, he agreed with Mr. Sarjant as to the great importance of arriving at some definite conclusion as to what was meant by furnace efficiency. Personally, he was in full agreement with the definition of efficiency used by Sir Robert Hadfield in his paper, *viz.*, that in industrial operations furnace efficiency is the ratio of the sensible heat plus the latent heat of the load to the total heat in B.Th.U. supplied. That, however, did not take into account thermal gradients and the transfer of heat through the furnace walls That really concerned the furnace maker and not the user, and in quoting figures of efficiency it would be very unwise in any way to include thermodynamic losses. His own experience of the electric furnace was that it was extremely adaptable; it could be built round a job to get the highest possible heat transfer, and usually the electric furnace was associated with a very high thermal efficiency; but the gas furnace could be adapted in the same way. It was only a question of design, and if gas furnaces were designed for the job then he believed there would be no difficulty in carrying out many operations in this way which were now regarded as possible economically only by the electric furnace, and he believed it could be done at a lower cost Another point about electric furnace design which had always appealed to him as of great importance was the power. When dealing with a furnace it must be treated as a heat engine; in other words, the rate at which work could be done was very important Usually, in operations relating to the bulk treatment of

metal over temperature ranges up to 1,000°C.—for carburising operations and other operations which demanded temperatures above that range, the electric furnace with some form of wire or bar element was the most suitable type—there was a limited amount of energy output per square foot of radiating surface available for the work, and that had been a very unfortunate circumstance as regards operating electric furnaces at big power inputs. He had in mind a carburising furnace in which, without any difficulty, no less than 950,000 B.Th.U. per hour—*i.e.*, power input—could readily be obtained with a gas furnace, the energy given up to the load allowing for an efficiency of about 30 per cent. would give an input of about 320,000 B.Th.U. per hour. With an ordinary wire-wound electric furnace of the same dimensions the actual rate of heating would be considerably less. Thus, on the question of through-put the electric furnace was limited compared with the gas furnace, so that for a given capacity it meant there would have to be an increase of the number of units in use with, of course, a corresponding increasing in the capital expenditure Whilst fuel cost of operations was very important it was frequently over-estimated, and time was very often a much more important factor in the final result For this reason there must be a reasonable power input to carry out the operations in a reasonable time.

Referring to the excellent paper by the American Gas Association, Dr. Walter remarked that the achievements in the gas industry in America corresponded with what had taken place in this country, and especially in the Midlands with which he had had most experience. During last year the increase in the output of gas used for industrial heating purposes alone in Birmingham was 238 million cu. ft., and as an indication of how the industrial load is increasing year by year, he pointed out that whereas in 1911 the quantity of gas supplied in Birmingham was 5 per cent. of the total output, during the twelve months ended March 31, 1928, it was not less than 21 per cent., and out of a total of approximately 14,000 million cu. ft. supplied no less than 2,840 million cu ft. were used for industrial heating purposes.

Mr. Robert Mond (Great Britain) said that as one of the pioneers of the introduction of the distribution of Mond or power gas under pressure, it had been a source of satisfaction to him to find that other people should have begun to study the problems which he and those associated with him had to familiarise themselves twenty-five years ago, when they started the central station for distributing producer gas in the district just north of Birmingham This problem had been partially worked out in the distribution of high-pressure natural gas in the United States, but there was a great difference between distributing a high methane 400 to 600 B.Th.U. gas and a 160 to 180 B.Th.U. gas which had to be provided for. At the same time there was another problem. He had always found it difficult to understand the very slow progress which the distribution of coke oven gas had made. It was a self-evident proposition that coke ovens should be heated with cheap producer gas from coke waste,

and that the rich coke oven gas should be distributed through pipes, because by distributing the poorer gas larger pipes had to be employed, and of course, these were more expensive. His father, Dr. Ludwig Mond, F.R.S., had proved its feasibility at the Winnington Works of Messrs. Brunner Mond & Co. in the early 'nineties, and had proposed its use in the Gasworks at Boston in 1900. He was pleased to see that our friends on the Ruhr were at last tackling the subject properly; the only thing that bothered him was that they had not done so very many years ago, and why, as the President of the Board of Trade had stated at the banquet, we were only now beginning to make enquiries into it.

These problems, like all technical problems, only fructified slowly, and it was necessary to have, with regard to them, a greater longevity and a great deal more patience than nature had endowed most people with, but the direction in which these things were going and the way they should be tackled, had been more or less self-evident from the beginning. The means of execution and making them practicable might be difficult and might take time to elaborate; nevertheless, it was a disappointment how slowly these things were progressing and how we handicapped ourselves by being so slow in all directions. As Mr Helps had just said, it was possible to get all kinds of temperatures from all kinds of fuel gases whatever their chemical constitution might be, the only question was that if a poor gas was used it was necessary to have a definite system of regeneration to get the temperature required The same thing applied very much to electric furnaces, although there it had not been properly worked out yet. In his different works the advantages and disadvantages of different electric furnaces were being examined, and he was hoping that considerable progress would be made in the use of electric heating for metallurgical purpose. A new type of reheating furnace had been running for three or four months with very good practical results in one of his firm's American works, and it was hoped that these results would give figures which it would be possible to communicate in a short time.

As regards the general problem of the utilisation of coal in this direction, there were several ways of looking at it. There were two diametrically opposed methods for dealing with coal; one was to try to get the maximum heat units which the coal contained, and the other was to try to obtain the maximum number of products from the coal. Whether there was going to be an unlimited consumption of the various coal products, for instance, the tar products, it was difficult to say, but no doubt as our knowledge advanced we should find increased use for them. All the methods which were discussed in the papers and the discussion were different ways of arriving at the same end, and it did not only apply to coal; there were the other fuels such as peat and lignite, and as a matter of fact, in some of the bigger installations erected in Italy a good many years ago, they were able to obtain a most satisfactory gas from peat, and for this purpose it was found possible to use peat up to the point where it was just sufficiently wet not to put out a fire; that meant over

50 per cent. water, and the gas was an excellent gas for gas eng The whole problem was a complicated one and practically had to be studied *de novo* in each case as to what was the best use to make of these solid fuel materials. There was no one royal road in any one direction. In recent years very great progress had been made and that progress was becoming much more rapid now. In the circumstances he felt confident that the frightful waste of these stored up resources of solar action would diminish in an increasingly rapid manner in the future.

CAPTAIN J. F. SHAW (Great Britain) drew attention to one of the papers which had not been mentioned, *viz.*, that on suction gas producers for motor vehicles, as it was a subject which the Fuel Research Board thought worthy of consideration, especially at the present time in the Dominions where the use of wood or charcoal fuel in producers might be a substitute for petrol. As a matter of fact, the Fuel Research Department was actively studying this matter at the present time. In this country we were definitely behind France in this matter of the use of charcoal for making producer gas to be used on lorries, first because our supplies were not sufficient, and secondly, because in cost it could not compete with petrol; but it appeared to be only a small step between the use of charcoal and the use of some form of coke—either low or high temperature carbonisation coke—and he did not think it would be many years before the whole of the heavy traction in this country was supplied with power in this way instead of using petrol. It seemed that the price of petrol was likely to go up, and he did not think the price of low or high temperature coke was likely to follow it very far.

As regards the use of steel tubes for pre-heating air, at the Fuel Research Station there had been in use since 1919 a set of ordinary boiler tubes for pre-heating the air supplied to the retorts. The gases left the retorts at between 900 and 1,100°C. and went past the tubes and pre-heated the air. There was an interchange of heat about 300°C., the gases leaving dropping about 300° and the air being heated up about 300°. These had been in use since 1919, and there had not been any signs of trouble or of a leaky tube.

MR. C. F. HAMMOND (Great Britain) remarked upon the few references in the papers to the trouble through stratification in burning different classes of fuel and particularly gas fuel, and said that, in view of the remarks of Mr. Helps and Dr. Waters it might be well to point out that the flame temperature of gases could be considerably increased if the question of stratification was looked after. His own recent experience showed that with ordinary town's gas or coal gas it was possible to reach an evolution of heat per cubic foot of combustion space which sounded very much like a fairy tale. The actual heat evolved from a furnace with which he was working had been steadily 15 million B.Th.U. per cubic foot of combustion chamber space per hour, which meant that the flame temperature must be very high indeed, about 3,000°C. He was in full agreement with Mr. Helps that 200 B.Th.U. gas was useful for high temperature

work, as he had found it possible to get 10 million B.Th.U. evolved per cubic foot of combustion chamber space with a producer gas of that quality. A point arising out of Dr. Walter's remarks was that in working with electric furnaces the temperature with wire-wound elements was limited to very small figures as far as the temperate gradient between the temperature of the furnace and the temperature of the work being heated up was concerned. The useful range of a wire-wound element was between 700 and 1,000°C. The rate at which heat could be put into a cold object was immensely increased if there were a very high temperature gradient, because then it was possible to get through the viscous gas film which collected on the gas surfaces very much more quickly. This placed a limitation at present on the electric furnace which need not be present in the case of a gas furnace or ordinary fuel fired furnace. He had carried out these combustion chamber tests in a combustion chamber composed of the special heat-resisting steel of which Sir Robert Hadfield had spoken, and under the conditions prevailing there was no apparent flaking of the surface of the combustion chamber wall. Special precautions were taken to see that the temperature did not rise above 1,200°C., but it was a very high performance, and one which reflected great credit on those responsible for producing such a steel.

MR. A. T. GREEN (Great Britain), said that he spoke as more or less representing the ceramic industry, and there were certain factors appertaining to the correct utilisation of energy in furnaces which could not possibly receive from such a conference the consideration due to them. In the ceramic industry the feature which governed the whole of the operations was the production of satisfactory ware with the least amount of "wasters" from the furnace, and in these circumstances, at the moment it was not desirable in that industry to have what might be termed a haphazard pandering to fuel economy. First and foremost, it was necessary to know definitely the actions that were taking place within the clay ware as the material was heated up, and to try to realise the ideal reactions in bulk production. That was a point of particular significance, because the term "the ceramic industry" was a comprehensive term. Clay was also a comprehensive term and included many varieties. These facts meant that there must be a definite flexibility in the apparatus used to fire the goods if the best results were to be obtained. For instance, Stourbridge clay contained normally a high percentage of carbonaceous matter which must be burned out at 500-700°C. over a long period. Certain Scottish clays, on the other hand, did not have that same characteristic and, therefore, the circumstances of the firing of the two clays were considerably different. Consequently, the design or manipulation of kilns firing these goods must be different. In one direction the design of ceramic kilns had progressed very considerably during the last decade, and this had resulted in a tremendous increase in efficiency. Such progress concerned the application of insulation. It was now becoming commonplace to use diatomaceous earth for the construction of kilns and furnace structures,

and in the ceramic industry generally there had been a wave of enthusiasm for its use during the past three years. The result was that sufficient data had been accumulated so that it had been possible to even up the temperatures within the fuel consumption to a very considerable degree. It had been estimated that about 40-50 per cent. of the heat that was previously lost in the structure could be saved by the use of diatomaceous earth in properly designed layers In constructing a kiln to fire earthenware bodies at 1,150° C. generally, a very much less bulk of brickwork was used than formerly. The actual refractory portion of a certain patented kiln was 2½ in. thickness of brickwork, on the top of which was 9 in. of diatomaceous earth and then a layer of common brick. Such a construction had reduced the total thickness considerably. At the same time, the amount of brickwork, which acted as a reservoir of unutilised heat, was very much reduced.

Mr. A. L. Forster (Great Britain) said he only took part in the discussion because of the remarks of Mr. Helps and the interesting speech by Mr. Robert Mond. He hoped he would not be considered unappreciative of the good work of the Conference if he suggested the desirability of having at the Conference a detailed study of the behaviour of the flame of a gas, because that would have simplified the consideration of the relative advantages of gas and electricity, just as Captain Sinnatt in one of the other sections had shown his semispheres and indicated what happened in the gasification of coal. Mr. Helps' work had been mentioned and it was now twenty-five years since Dr. Mond first pressed the claims of producer gas as a means of distributing energy. Some years ago he (Mr. A. L. Forster) had substituted electricity as a means of heating, for town's gas, and now he was substituting washed producer gas for a higher quality gas, such as town's gas, and whilst he was not able to give the full details he had found considerable difficulty in getting high temperatures, although the trial was very carefully arranged Plenty of gas was put in and the thermal units were about the same, but the trouble he rather thought was due to the character of the flame. One speaker had mentioned the danger of stratification. He hoped he would be pardoned for making his suggestion, because he was not quite sure that people should make suggestions unless they could fill the gap and he could not do that in this instance; however, he did not think the detailed study of flames was the work of an engineer. Delays in progress with fuel were due to the reluctance which we all experienced, and perhaps somewhat naturally, to incur heavy capital expenditure which might not be justified by the commercial saving in fuel There was a certain time factor in is, which was very important; and, therefore, it was necessary for those concerned to make up their minds among themselves as to what was the term of years ahead during which a recovery might be expected of the capital expended to-day. If capital expenditure to-day was limited to that which would give a certain legitimate return on the outlay at to-day's figures, we should be taking too short a view. Experience over a fair number of years showed a

steady increase in the cost of energy or the cost of fuel at any rate, and if, instead of taking the short view we took a longer one, there would be found much more inducement to incur capital expenditure to save fuel, apart from the ancillary questions of adaptability, and so on.

The Session closed with a cordial vote of thanks, proposed by Mr. R. P. Sloan, to the Chairman, Vice-Chairman, authors of papers and speakers in the discussion.